GLASS

Technology Roadmap Workshop

September 1997

Workshop held in
Alexandria, Virginia
on April 24-25, 1997

Sponsored by the

U.S. Department of Energy
Office of Industrial Technologies

and

Corning, Incorporated
Ford Motor Company
Pilkington Libbey-Owens-Ford
Praxair, Incorporated
Techneglas, Incorporated

Prepared by
Energetics, Incorporated
Columbia, Maryland

Report of the

Glass Technology Roadmap Workshop

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Prepared by
Jack Eisenhauer
Paget Donnelly
Shawna McQueen
Ann Monis
Joan Pellegrino
Jocelind Julien

ENERGETICS, INCORPORATED
Columbia, Maryland

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1 Executive Summary

The American glass industry has taken an important step in defining its future in response to changing market and business conditions. The industry faces exciting new opportunities but also serious challenges. New technology is expected to play a pivotal role in addressing these conditions and create a competitive advantage for U.S. glass manufacturers. Advanced glass technology can lower production costs and create high-profit, innovative products to compete with other materials and foreign competitors.

The complexity of new products and the intensity of global competition require that glass producers adopt new strategies for developing and applying innovative technologies. Recognizing the importance of cooperative technology planning, the U.S. glass industry organized a *Glass Technology Roadmap Workshop*, held April 24-25, 1997 in Alexandria, Virginia. This collaborative workshop brought together 38 experts from the glass industry, universities, and the national laboratories to help identify key targets of opportunity, technology barriers, and research priorities in the glass industry. The 1½-day workshop, which was sponsored by the U.S. Department of Energy, Corning Incorporated, Ford Motor Company, Pilkington Libbey-Owens-Ford, Praxair, Inc., and Techneglas, Inc., addressed the needs of the entire glass industry, including flat glass, container glass, specialty glass, and fiberglass.

The workshop grew out of a collaboration between the glass industry and the U.S. Department of Energy's Office of Industry Technologies (OIT) to help increase energy efficiency, reduce waste, and increase productivity within the domestic glass industry. In January 1996, the industry outlined its long-range vision for maintaining and building its competitive market position in the document *Glass: A Clear Vision for a Bright Future*. The industry reaffirmed its commitment to the goals contained in this vision by signing a compact with Secretary of Energy Hazel O'Leary. This partnership will enable the industry and the federal government to align their research and development efforts to meet common R&D goals.

The core of the workshop consisted of four facilitated sessions in which participants explored in detail the critical research needs in the areas of **Production Efficiency, Energy Efficiency, Environmental Protection and Recycling,** and **Innovative Uses of Glass**. Within these four focus areas, participants identified several important areas of research that will be essential in developing new process technologies and new glass products. These are summarized in Exhibit 1-1.

Exhibit 1-1. Priority Glass Research Areas

Process Research	Product Research
• Modeling and Verification • Sensors, Measurements, and Controls • Process Design • Melting, Fabrication, and Forming Processes • Material Needs • Enabling Technology • Emission Characterization and Control • Post-Market Waste Utilization • Radical Innovations	• Optical and Photonic • Electrical and Electronic • Solar Applications • Composites • Structural Uses • High Strength/Other Properties • Farming • Environment and Waste • Fundamental Research and Analysis

Workshop participants identified over 130 specific research needs in the four focus areas, of which about half were considered to be priority. These research ideas were analyzed to determine the time frame in which each research activity is expected to have an impact in a commercial application or product. Research activities were assigned to defined time frames: near (0-3 years), mid (3-10 years), and long (beyond 10 years). In addition, some research is expected to continue over all time periods and produce valuable results in each. Exhibit 1-2 lists selected high priority research needs organized by time frame.

Participants also conducted an analysis of the expected commercial payoff and risk associated with each research activity. Risk was defined as the probability that the research would not result in a successful outcome, and payoff was interpreted as being a measure of commercial profitability and/or increased glass shipments. Participants presented their results in an open forum, which helped to identify a number of commonalities in research needs across the individual groups. The results of these efforts are described in this report. Together with the work done by four industry subcommittees, these results will help to shape a comprehensive technology strategy for implementing glass industry goals. In closing remarks, many participants expressed concern that the momentum of the workshop not be lost but be used to move forward with the development of a technology roadmap and the pursuit of mutually beneficial collaborative research opportunities.

Exhibit 1-2. Selected High Priority Research Needs for the Glass Industry

Time Frame	Production Efficiency	Energy Efficiency	Environmental Protection and Recycling	Innovative Uses for Glass
NEAR (0-3 Years)	• Produce coupled models that simulate combustion space and the glass melt	• Establish test facility for model verification	• Develop and evaluate refractories for melting systems	
MID (3-10 Years)	• Develop intelligent control of production and fabrication processes • Develop integrated process control strategies	• Basic materials research for heat recovery applications	• Develop predictive emission modeling tools • Develop cost-effective separation and sorting techniques for post-consumer glass • Develop durable, high-temperature sensors for flow temperature, and gas composition • Develop integrated control systems to link production with emissions • Develop more efficient, lower-cost oxygen production	• Conduct research to increase understanding/ model surface modifications, surface interactions, surface chemistry, and reactions at the glass interface • Explore use of microwaves and ultrasonic waves for control of glass shape and other process parameters
LONG (10+ Years)	• Develop longer-lasting non-refractory materials	• Explore new alternative glassmaking technologies - alternative melting methods - new, large-volume processes - revolutionary small-scale glassmaking processes • Design and develop non-traditional refining techniques	• Develop new heating mechanisms to economically melt glass without noxious emissions	• Achieve glassmaking process integration through models, sensors, and feedback loops
ALL (0-10+ Years)	• Determine corrosion mechanisms of refractory composition • Improve hot glass contact materials (e.g., molds and rolls)	• Develop accurate, validated melter models that include batch melting, combustion, and glass flows • Conduct research to improve refractories		• Develop more effective sensors for measurement and control of temperature, viscosity, redox reactions, gas velocity, and colorants

2 Plenary Session

Introduction

Glass is an integral part of the American economy and everyday life. It is essential for food and beverage packaging, for lighting homes and businesses, for communicating sounds and visual signals, and for the construction of all types of buildings, from hospitals to high-rises. Glass is used for a myriad of consumer products ranging from ordinary cookware to televisions, and is an essential component in automobiles and trucks. However, glassmaking is also very energy-intensive and the industry has made great progress in reducing the environmental consequences of fuel combustion in glass furnaces. For example, the introduction of oxy-fuel firing, in which fuel is burned in a pure oxygen environment, has reduced emissions of greenhouse gases and critical air pollutants such as NO_x by as much as 50 percent or more using this technology.

The unique attributes of glass (transparency, chemical durability, optical properties, low cost, total recyclability) and the abundance of raw materials from which it is made account for the ubiquity of glass products in our society and ensure its continued success. But while market opportunities are expanding, glass must increasingly compete with various materials (e.g., plastics, aluminum) that may offer lower cost, lighter weight, higher strength, or other competitive advantages. In the future, glass companies must be able to provide superior products with unique properties that make them more desirable than products made from other materials. These new glass products will require the development of novel process technologies that reduce production costs and enhance desirable characteristics. Innovations in glass composition and glass properties will be needed to support the expansion of glass into completely new markets.

The glass industry vision, *Glass: A Clear Vision for a Bright Future,* recognizes the importance of past technological achievements and the potential of future technological advances to accomplish a variety of glass industry goals. These goals, listed in Exhibit 2-1, will be instrumental in guiding glass technology priorities among glass manufacturers, government technology programs, and research performers within universities and national laboratories.

Following publication of the glass vision, four industry subcommittees were formed with participants from various segments of the glass industry to begin developing a *technology roadmap*. When complete, the roadmap will provide a comprehensive blueprint of the research that is necessary to achieve the market, business, and technology goals identified in the glass vision. The subcommittees addressed each of the critical research areas outlined in the vision:

- Production Efficiency,
- Energy Efficiency,
- Environmental Protection and Recycling, and
- Innovative Uses for Glass.

Exhibit 2-1. Glass Industry Goals

Glass Industry Goals from *Glass: A Clear Vision for a Bright Future*
1. Reduce production costs by at least 20% below 1995 levels 2. Recycle 100% of all glass products in the manufacturing process, where consumption is greater than 5 lb/capita 3. Reduce process energy use from present facility levels by 50% toward theoretical energy use limits 4. Reduce air and water emissions by a minimum of 20% through environmentally sound practices 5. Recover, recycle, and minimize 100% of available post-consumer glass 6. Achieve 6 sigma quality control through automation, process control, optimized glass composition/strength, and computer simulation 7. Create innovative products that broaden the marketplace 8. Increase supplier and customer partnerships in raw materials, equipment, and energy improvements

The *Glass Technology Roadmap Workshop* described in this document is an important step in completing the roadmap. The workshop provided an opportunity to verify and validate the initial findings of the subcommittees and gain additional input and insight by expanding participation to include a broader cross section of glass producers, research performers, and industry experts (see Appendix A for the participant list). The 1½-day meeting included a plenary session, four parallel breakout sessions, and a summary session (see Appendix B for the workshop agenda). The plenary session provided an opportunity for each subcommittee chair and the DOE glass program manager to summarize their activities to date. Subcommittee chairs discussed the results of previous meetings and their initial set of research priorities that were developed in March 1997 based on the glass vision. These priorities are summarized in Appendix C.

Production Efficiency Overview (Mr. Vincent Henry, Ford Motor Company, Chair)

New research and development in production efficiency is essential to business growth and survival and will help the industry be more competitive and efficient. The Subcommittee on Production Efficiency is focused on improving the efficiency of glass production, including improved manufacturing processes and new techniques that maximize glass strength and quality. The objective of the subcommittee is to "*produce more quality glass products in a timely manner at lower costs, without adversely impacting environmental emissions*". Subcommittee membership is large and diverse. Its 16 members include representatives from every segment of the glass industry, the national laboratories, and DOE.

The Subcommittee has met four times to set priorities for a comprehensive research portfolio. Several common areas have been identified that could lead to increased production efficiency. A survey form was circulated to subcommittee members to further clarify research priorities. This survey revealed specific areas of interest within major research areas. The workshop is seen as an opportunity to include the views of additional stakeholders from all segments of the glass industry. Once research priorities are set, the Production Efficiency Subcommittee hopes to build a coalition of industry, academia, and government agencies to accomplish the research agenda. Mr. Henry's presentation is included in Appendix D.

Energy Efficiency Overview (Dr. James Shell, Techneglas, Inc., Chair)

The focus of the Energy Efficiency Subcommittee is to identify and pursue technology research that can help reduce the gap between current process energy use and the theoretical minimum by 50 percent. The Subcommittee consists of nine members from the glass industry, one from a national laboratory, one from the Institute of Gas Technology, and a DOE representative.

The Subcommittee has identified four basic pathways for achieving energy efficiency goals. These may be summarized as follows:

- Optimizing electric boost to reduce total energy consumption
- Improving furnace design and operation to maximize combustion efficiency
- Recovering and reusing waste heat from oxy-fuel furnaces
- Producing oxygen more efficiently for oxy-fuel firing

The Subcommittee has identified research needs for different types of furnaces. Among the highest priority projects are refractories for crown and breastwalls and physical validation of mathematical models to improve modeling capabilities. Dr. Shell's presentation is included in Appendix D.

Environmental Protection and Recycling Overview (Mr. Kevin Fay, PPG Industries, Chair)

The goal of the Environmental Protection and Recycling Subcommittee is to achieve cleaner operations with lower environmental control costs and to increase glass recycling. The Subcommittee consists of six members from the glass industry, one from a national laboratory, and one DOE representative.

The Environmental Protection and Recycling Subcommittee was formed in mid-1996 and used conference calls to brainstorm research needs. Summaries were developed by the four key glass industry segments. A workshop in October 1996 helped to refine these needs and a report of the findings was presented in February 1997.

The highest overall environmental protection priority is to develop improved oxy-fuel firing technology as a means to reduce air pollutants. The medium priority need is to develop alternative raw materials and improve batch preparation and preheating processes, as well as improved furnace designs, to lower particulate and gaseous emissions.

In recycling, the team's highest priority is to improve sorting and preparation of post-consumer wastes, with specific needs in automatic color separation, removal of contaminants, and creation of new cullet markets. The medium priority need is to secure a more reliable outlet for used refractories. Mr. Fay's presentation is included in Appendix D.

Innovative Uses Overview (Mr. Frederic Quan, Corning, Inc., Chair)

The Innovative Uses Subcommittee is distinct from the other subcommittees because it focuses on new glass products rather than process improvements. This subcommittee seeks new applications for glass that reflect a higher technical content and create a positive impact on the glass industry. The major challenge for this subcommittee is to define areas of precompetitive research that are appropriate for investment. The Subcommittee includes seven representatives from the glass industry and a DOE representative.

The glass industry needs new products. Too many of its current products are mature, and a higher-margin product mix is needed. Traditionally, support for R&D has been limited, yet innovation is needed. The Subcommittee has adopted a well-structured process for its technology roadmap activities. It includes identifying key drivers that affect products and processes and the application of criteria to prioritize opportunities based on industry impact, time to market, and market size. Acceptable project ideas are prioritized based on profitability, market size, and technical risk.

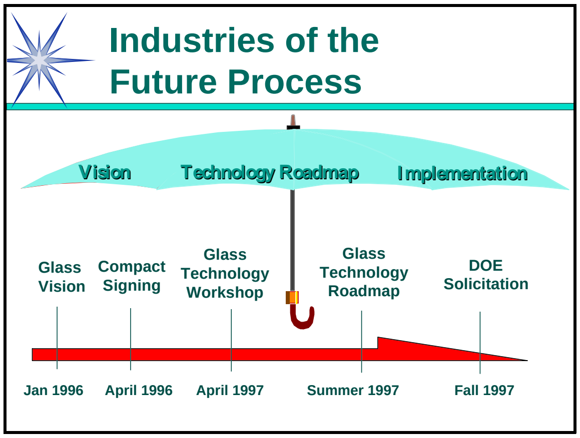
The Subcommittee used a brainstorming session at the Glass Problems Conference in October 1996 to develop drivers, products, and processes. The Subcommittee used this input to organize lists and developed a generalized schedule of product timing and market size for each product. Mr. Quan's presentation is included in Appendix D.

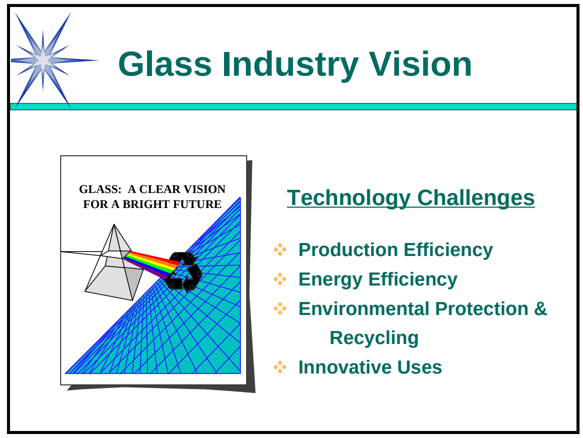
The DOE-Glass Industry Partnership

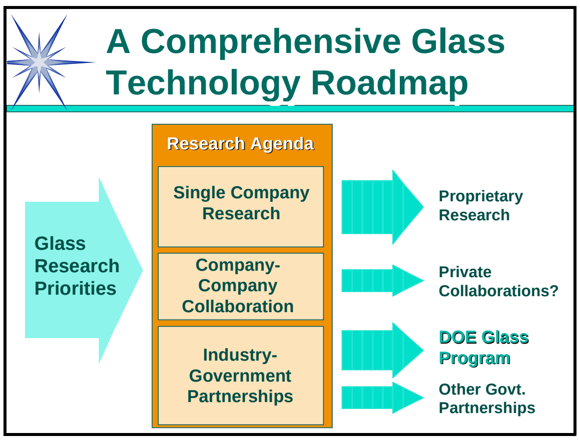
Mr. Theodore Johnson, Glass Team Leader of the U.S. Department of Energy's Office of Industrial Technologies (OIT), summarized the excellent progress that has been made in bringing together the interests of the U.S. glass industry and the federal government. The common ground provides the basis for the DOE-industry partnership to tackle key technology challenges and make the glass industry more efficient, clean, and competitive (Exhibit 2-2). He reiterated the four key challenges of the glass industry vision and reviewed OIT's Industries of the Future process.

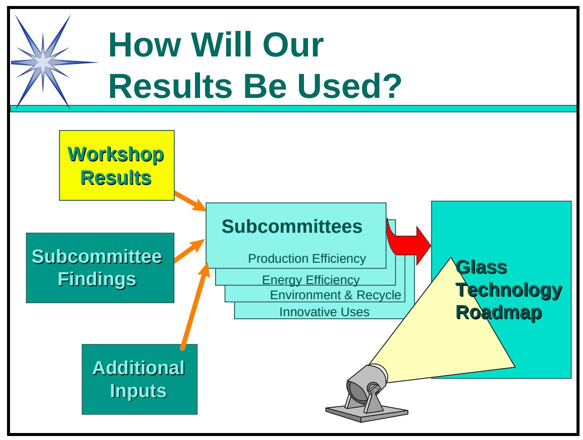
In describing the workshop, Mr. Johnson impressed upon the participants that the discussions should not be limited just to areas where the OIT Program can participate in R&D. The glass technology roadmap should produce a comprehensive technology plan that includes research that can be pursued by individual companies, industry collaborations, and government-industry partnerships. The results of the workshop will be combined with the previous work of the subcommittees and some additional analysis to produce a draft roadmap that will be circulated within the industry for comments. The draft will then be revised and published.

Exhibit 2-2. Glass Technology Roadmap Presentation Summary









Workshop Structure

Exhibit 2-3. Work Group Facilitators

1) Production Efficiency	Jack Eisenhauer
2) Energy Efficiency	Richard Scheer
3) Environmental Protection and Recycling	Shawna McQueen/ Paget Donnelly
4) Innovative Uses	Joan Pellegrino

Mr. Jack Eisenhauer of Energetics, Incorporated reviewed the agenda and the instructions for the participants. The workshop consisted of a plenary session, breakout work sessions, and a summary session. The core of the workshop was a group of four parallel breakout sessions—one for each subcommittee area—that were professionally facilitated by Energetics staff (Exhibit 2-3). The workshop process was reviewed, including the purpose, scope, and structure for the sessions (Exhibit 2-4).

Exhibit 2-4. Workshop Format and Process

Purpose

This workshop was part of an effort by the glass industry to develop a technology roadmap for achieving identified market, industry, and technology goals. The purpose of the workshop was to

- define glass industry performance targets.
- identify critical technology barriers facing the glass industry.
- identify near-, mid-, and long-term research needs for overcoming barriers.
- indicate the relative priority of research opportunities.

The results of the workshop will be used directly in the development of the *Glass Technology Roadmap*. When completed, this *Roadmap* will provide a complete picture of the near-, mid- and long-term research needs of the glass industry.

Format and Scope

The workshop was a 1½-day facilitated meeting that brought together technical experts from the glass industry and related organizations to identify research needs and priorities through an interactive discussion. The workshop covered the full spectrum of research needs and opportunities of the glass industry.

- The scope of this workshop was limited to exploring technology-based solutions.
- Participants considered research that addresses near- (0-3 years), mid- (3-10 years), and long-term (beyond 10 years) industry needs.
- The workshop did not result in any decisions to fund specific R&D projects. Instead, it produced sets of R&D options based on judgements of technical and market needs.

Workshop Structure

The workshop was a product-oriented meeting in which participants had active roles. The workshop consisted of three separate sessions spread over 1½ days. Each session is described below.

Plenary Session: Chairs of the Glass Industry Subcommittees and the Glass Industry Team Leader from the U.S. Department of Energy gave overviews of the progress and status of the technology roadmap process. The session also included instructions for the breakout groups and a description of the workshop process.

Work Group Sessions: The participants were divided into four smaller groups that met separately to address technology issues within four key topic areas: Production Efficiency, Energy Efficiency, Environmental Protection and Recycling, and Innovative Uses for Glass. Participants of each group described the major technology barriers to achieving long-term glass industry goals in their topic area and identified the research that will be needed to overcome these barriers. Participants were then asked to identify the top, high, and medium priority research needs. For each research activity, the participants analyzed the appropriate time frame (near, medium, and long) and the relative payoff and risk of each research idea.

Summary Session: All workshop participants convened to hear concise summaries of the results of each work group. After each presentation, group members fielded questions and engaged in a discussion of the findings. At the conclusion of the presentations, each individual had an opportunity to provide concluding remarks and suggest next steps.

3 Production Efficiency

The Production Efficiency Group examined opportunities to improve the efficiency of glass production, including improved manufacturing processes and new techniques that maximize glass strength and quality. In particular, production efficiency gains are expected to result from improved melting and refining processes that will increase product yield while lowering energy and other production costs. While many of the technologies examined by this group coincide with the interests of the Energy Efficiency Group and the Environmental Protection and Recycling Group, the Production Efficiency Group considered *all* aspects of the production process and their impact on energy use, glass quality, product yield, waste generation, and production costs.

Production Efficiency Work Group

William Augsburger	Techneglas, Inc.
Donald Foster	Lawrence Berkeley National Laboratory
Robert Gallagher	Sandia National Laboratory
Peter Gerhardinger	Pilkington Libbey-Owens-Ford
John Goodyear	Ford Motor Company
Michael Harris	Corning Incorporated
Vincent Henry	Ford Motor Company
Christopher Jian	Owens-Corning
John McConnell	PPG Industries, Inc.
Ronald Schroeder	Praxair, Inc.
Charles Sorrell	U.S. Department of Energy
George Vachtsevanos	Georgia Institute of Technology

The Production Efficiency Group included representatives from glass producers, glass suppliers, national laboratories, universities, and government. Three segments of the glass industry were represented including producers of flat glass, specialty glass, and fiberglass. While there were no representatives from the container segment, many of the technical issues that were discussed addressed generic needs of glass melting and process control. Eight of the twelve participants in the work group are also members of the Production Efficiency Subcommittee, including its Chair, Vince Henry. Two members of the Subcommittee participated in other breakout groups.

Production Efficiency Targets

Production efficiency improvements can contribute to all eight of the goals specified in the glass industry vision. However, the greatest contributions will be realized in five of those goals:

- Reduce production costs by at least 20 percent below 1995 levels.
- Reduce process energy use from present facility levels by 50 percent toward theoretical minimum.
- Achieve 6 sigma quality control in some processes.
- Reduce the time to bring a product to market.
- Achieve zero waste emissions.

With these broad goals as the base, additional performance targets for production efficiency were identified. Many of these performance targets reflect intermediate goals that can be achieved before 2020, or goals for specific production operations. Exhibit 3-1 lists the additional performance targets for production efficiency.

Quantifiable measures could be identified for several targets, while other targets were more appropriately stated as continual improvement goals. The targets listed in Exhibit 3-1 should be considered preliminary and may require additional assessment and refinement.

Exhibit 3-1. Performance Targets for Production Efficiency

Quantitative Targets
• Reduce capital costs by 25 to 50%. • Improve operating efficiency by 25% (yield x cycle time x up time). • Double sales per capital investment ($ per $). • Improve optical quality by 50% while maintaining yield. • Eliminate all sources of surface damage. • Extend furnace life (e.g., 5 more years or 30%). • Reduce capital investment or increase capacity by 35% through process and equipment innovations. • Set goal for "lowest process loss".
Qualitative Targets
• Improve process yield and quality while lowering operating costs. • Better understand the distribution of production costs. • Improve working conditions (e.g., ergonomics, controls, operator training). • Optimize processes through a better understanding of the chemistry and physics involved.

Technology Barriers

Opportunities to improve the efficiency of glass production are inhibited by several key technical and research-related barriers (Exhibit 3-2). The most significant technical barriers fall within the areas of process design and control and materials performance and cost. Other types of barriers include thermal performance, fundamental research, information transfer, and non-technical issues.

The lack of effective in-process sensors and control systems is the most serious barrier to better production efficiency. Accurate process control is the most effective way to optimize

Exhibit 3-2. Technology Barriers to Achieving Production Efficiency Goals

(● = High Priority)

Materials Performance & Cost	Process Design and Control	Thermal Performance	Information Transfer	Non-Technical Barriers	Fundamental Research
Materials performance limitations ●	Lack of integrated product and process controls	Means of removing heat faster	Lack of access to outside industry technology information	Anti-trust on technical issues	Lack of complete understanding of the fundamental physics
Need refractory materials that can withstand high temperature, erosion, corrosion, <u>and</u> not affect glass product ●●	Lack of better in-process sensors and process control systems ●●●●●	Effectively getting energy into the glass ●	Lack of an accessible integrated database	Non-technical issues - plant conditions - lack of training - management issues - short-term profit focus - alternative pay is better	Scale-up of fundamental knowledge ●
Surfaces that stand up to surface temperature	Accurate high temperature physical properties		Lack of access to high performance super computers	Management dedication to R&D	How to fundamentally change the way glass is melted and processed
Lack of investment from refractory and equipment producers	Need to vectorize models (better control)		Lack of good dissemination of information	Need a long- term commitment from funding agencies (Congress) ●	
Lack of lower-cost oxygen (ATP input idea)	Do not have "fear of failure" quick data turnaround		Need for benchmarking for pre-competitive processes - Industry complexity makes bench-marking difficult (many parameters)	R&D often seen as expendable investment - how much R&D dollars today vs. yesterday	
Need for better quality raw materials	Processes are large and highly interactive				
Lack of low-cost, high-performance, high-temperature robots	Better understanding of the operation of oxygen furnaces				
Need for better materials property data	Lack of understanding of all the control variables and their interrelationships				
	Need high quality laboratory data sets (instrumentation is not robust - use lab instrumentation)				
	Lack of flexibility to change products on a line - difficult to change over				
	Does process limit product innovation				
	Discrete problem identification (defect source)				

production within existing furnaces and production lines. However, without accurate and reliable sensors and their associated control systems, production managers may be unable to determine whether their processes are operating efficiently. Sensors are also needed to help gather operating data to develop better models. With better sensors and controls, engineers can begin to develop a better understanding of all the control variables and their interrelationships. This is particularly appropriate for large, highly integrated glass production processes in which the ability to quickly identify and correct problems is important.

The lack of cost-effective materials that perform adequately in glass furnace environments is another key barrier. In particular, there is a strong need for better refractory materials that can withstand very high temperatures, erosion, and corrosion, but not adversely affect the quality of the glass product. The lack of adequate refractory materials may be the result of limited investment in research and development on the part of refractory and equipment producers. Another materials-related impediment is the performance limits of materials that contact the glass and are exposed to harsh operating environments. In general, surface materials must do a better job of standing up to high-temperature environments. Advancement in these areas has been partly limited by a lack of good data on materials properties. Other materials needs include lower-cost oxygen and better quality raw materials.

A lack of fundamental research limits our understanding of the underlying physics involved in glassmaking. A stronger understanding could lead to the discovery of new ways to fundamentally change the way glass is melted and processed. Once fundamental knowledge is gained, the industry faces additional barriers in scaling-up technologies from bench to pilot and full-scale processes.

Thermal performance in the glassmaking process is another technical issue. In particular, there is a need to develop techniques to effectively transfer energy into the glass as well as rapidly remove heat from the glass.

Associated with these barriers are a variety of non-technical barriers that limit technical achievement. Of these, the lack of a long-term commitment to R&D by federal agencies is among the most critical. Other non-technical barriers include antitrust concerns, corporate management dedication to R&D, a short-term focus on profits, and the view that R&D is a non-essential investment. A special type of non-technical barrier is the lack of effective information transfer. In some cases, technical information may exist but is not readily accessible by the engineers who could benefit from it. For example, scientific and technical discoveries outside of the glass industry are often missed. Accurate benchmarking of precompetitive processes would also benefit glass producers, however the complexity of glass production, particularly the large number of process parameters, make benchmarking difficult. Access to high-performance super-computing resources is currently limited but could benefit glass modeling efforts. Finally, the glass industry lacks an accessible, integrated database that would benefit researchers and process engineers.

Research Needs

Significant improvements in production efficiency will require near-, mid-, and long-term research strategies that address technology barriers in an integrated way. Critical research is needed in areas that are essential for efficient glass production: sensors and controls, modeling, materials, process design, and radical innovations (Exhibit 3-3). Specific research pathways in these areas must be defined to ensure that successful research results can be incorporated into new processes and systems. Any successful research strategy must also identify mechanisms to provide the necessary R&D investments and scientific infrastructure to implement a coordinated glass research plan.

Advancement in sensors and controls is perhaps the most important requirement for improving the efficiency of glass production. Research in this area is essential for optimizing numerous production parameters and fine tuning processes. Most sensor research can be accomplished in the near-term, while intelligent systems that use smart sensors and integrate process control will be realized in the mid-term. The highest priority in this area is to develop the technology that will enable intelligent control of production and fabrication processes. This will require improvements in sensor technology, including robust contact and noncontact temperature sensors, gas combustion species sensors, and velocity sensors. With appropriate investment, most of these technologies can be developed within about three to five years. Even more important, however, is the development of reliable smart sensors that can indicate when they are drifting or failing and that have the capability to self-calibrate. Integrated control strategies, which can assimilate a large variety of process data and optimize production by controlling combustion and melt parameters, are an important mid-term research priority. Other key research is needed in the mid-term to develop diagnostics, prognostics, and condition-based maintenance; to develop the capability for three-dimensional measurements above and below the melt line; and to develop multiple wavelength infrared measuring devices.

Modeling is required to help simulate glass processes and improve understanding of the dynamics of combustion and the glass melt. In the near-term, research on coupled models that can simulate the glass melt and combustion space (including batch behavior) is a highly important priority. Mid-term modeling needs include real-time dynamic modeling of process control and the computer capability for identifying sources of defects. Related to all these is the need for some form of validation of the developed models with empirical and other data.

Materials research is needed to improve the performance of materials that must withstand the hostile environment of the glassmaking process. Many research priorities encompass activities that can produce technical contributions in all three time periods (near, mid, and long). The most important materials need is to better understand refractory composition, particularly corrosion mechanisms in the oxy-fuel environment. However, there is also a strong need to develop non-refractory materials that are better and longer-lasting.

For flat glass, this could include advances such as improved anealing lehr rolls that are self-lubricating and won't stain the glass. For containers, this could include improved forming and mold materials. Important near-term materials research needs include the capability for systematic measurement of physical properties as a function of temperature and improved

Exhibit 3-3. Major Research Needs for Production Efficiency

	Sensors, Modeling, and Controls	Modeling	Materials	Process Design	Non-Technical
NEAR-TERM < 3 years	Develop improved robust temperature sensors ●○○○○ Develop robust sensors for atmospheric gas measurements (exhaust and combustion) ○ Research to detect and eliminate see-through distortion (flat only) Develop on-line stress measurement (flat only)	Coupled glass melting and combustion space modeling ✪✪✪●●●○○ Faster modeling - instantaneous - high-speed	Develop improved materials for sensors so it won't affect glass quality Research on systematic measurement of physical properties as a function of temperature ✪	Develop methods to recycle or rescrap waste (fiberglass) Develop FMEA (Failure Mode and Effect Analysis) Develop of pre-heating and batch and cullet - focus on throughput ✪●○ Improved thermal quench processes (flat glass) ○	Support the Center for Glass Research (refractories) ○○ Integrate DOE glass research with and through CGR
MID-TERM 3-10 years	Develop integrated control strategy ✪●●● Develop smart sensors that are self-calibrating, self-detecting, and reliable ●●●○ Develop 3-D thermal measurements above and below meltline ○ Develop 3-D velocity measurements above and below glass Intelligent control of production and fabrication process ✪✪✪ Develop diagnostics, prognostics, and condition-based maintenance ●○ Develop multiple wavelength infrared measuring devices ○	Develop real-time dynamic modeling of process control ○ Develop computer capability for defect sources - ability to work backward to source problem ●○ Research methods to validate models - develop new data ●●○	Develop monolithic refractory design (monolithic crowns)	Improve oxy-fuel firing systematically - look at it as a system ○○ Research to optimize furnace size ● Systematic look at fast glass change melter - multiple products ○ Quick removal of thermal energy from glass	Support a research facility aimed at the glass industry R&D (furnaces) ●●
					Radical Innovations
LONG-TERM > 10 years			Develop longer lasting materials in addition to refractories ✪✪●● Fundamental research in new materials Research alternate raw materials for glass production		Fundamental research on new ways to make glass Fundamental research in new materials
ALL TIME FRAMES			Hot glass contact materials - better mold materials for glass container manufacturing - improved Lehr roll materials that are self-lubricating and won't stain glass ●●●○○ Determine corrosion mechanisms of refractory composition ✪●●○		

✪ = Top Priority ● = High Priority ○ = Medium Priority

sensor sheathing materials that won't affect glass quality. In the longer-term, fundamental materials research should be supported as well as research on alternative raw materials for glass production.

Process design improvements will also be needed in a variety of areas. In the next three years, the highest priority research will be to develop pre-heating of the batch and cullet with a focus on increasing throughput. Systematic improvement of oxy-fuel firing is needed in the mid-term with attention to heat flux measurements and consideration of totally new furnace designs that can optimize performance. Mid-term research is also required to optimize furnace size for a variety of production characteristics. Other research priorities include improving thermal quench processes and taking a systematic look at fast glass change melters that can handle multiple products.

Looking toward the long-term, the glass industry must also consider radical innovations that could fundamentally change glass processing. This effort will include fundamental research on alternative approaches to making glass. This must be accompanied, however, by research to increase the fundamental understanding of the chemistry and physics of glassmaking.

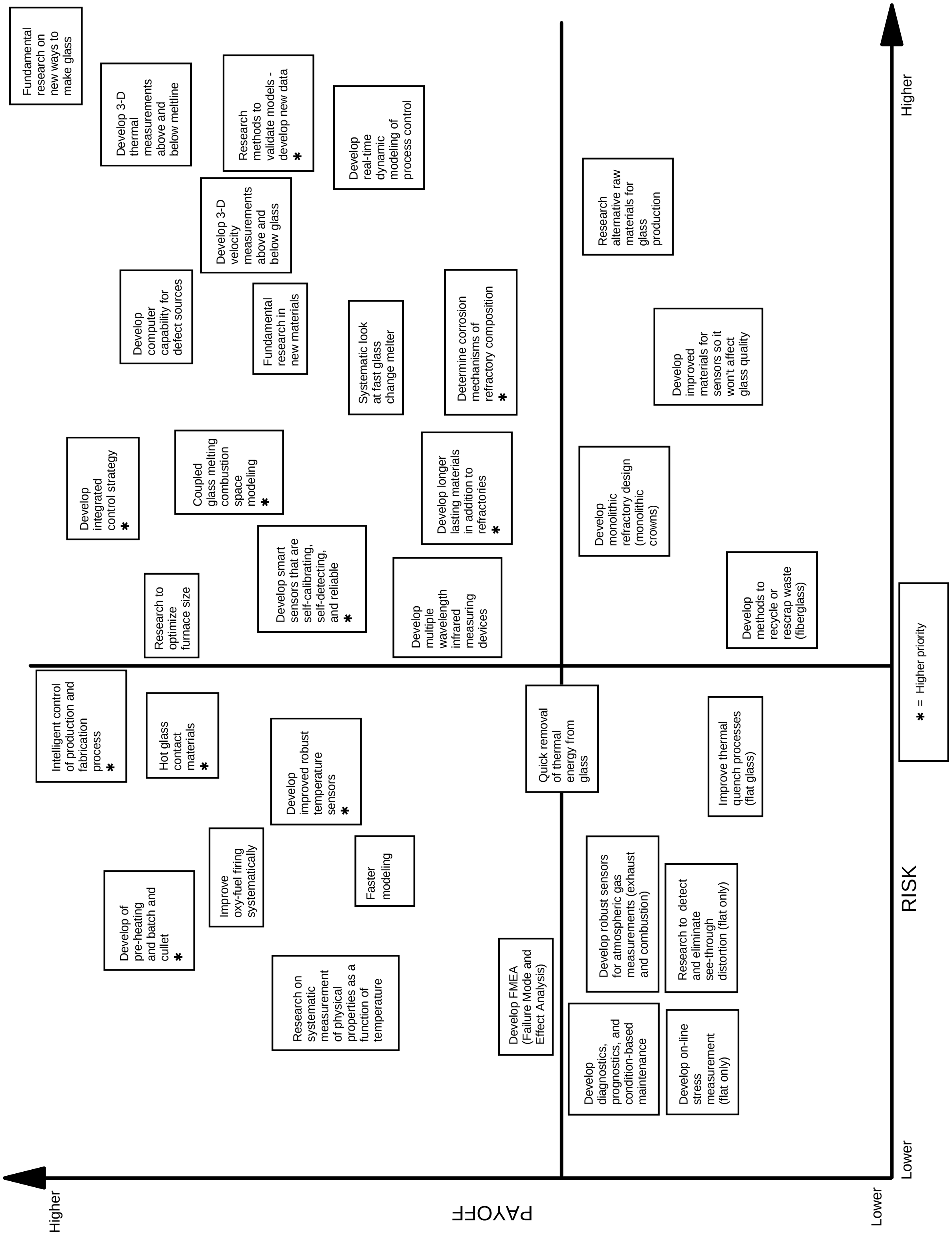
Finally, the glass industry will need a sound infrastructure to implement its R&D agenda. It is now widely recognized that the complexity of technical production issues coupled with the limited financial resources of individual glass companies requires that new approaches be developed for funding and performing glass R&D. These approaches are all appropriate for near-term action. Opinions vary on the appropriate role of the Center for Glass Research, with some advocating continued or expanded support, particularly in the area of refractories. There is also a priority need for a research facility that will focus on the needs of the glass industry, particularly furnaces and combustion issues.

Payoff and Risk

Each research idea offers a certain potential payoff and carries a certain level of risk. Payoff has been broadly defined as a measure of both increased glass product shipments and increased profitability for the glass industry resulting from a research idea. Risk is defined as the probability that the research will result in a successful outcome. By definition, all of the identified research ideas offer significant payoffs because they were deemed to be critical to overcoming major technology barriers. Accordingly, a relative scale is used to measure the level of payoff; that is, it indicates *higher* and *lower* payoffs—not high and low. It should also be noted that some research offers high payoff but only in specific segments of the glass industry. Therefore, some research may offer moderate industry-wide potential but higher payoff within specific segments. The level of risk is also relative and can change depending on available opportunities to share risk among several participants through partnerships and cost-sharing. Participants were instructed to consider risk *a prior*, without regard to funding arrangements. The results of this effort are shown in Exhibit 3-4.

As would be expected, most of the top priority research ideas offer the highest payoffs, regardless of risk. Some of the highest payoffs are expected to come from important advances in sensors and controls, specifically the development of intelligent control of production and

Exhibit 3-4. Payoff vs. Risk for Production Efficiency Research



fabrication processes and the development of integrated control strategies. Other high-payoff areas are the development of pre-heating systems for the batch and cullet and fundamental research on entirely new ways to make glass.

Research risk generally increases as the research benefits occur further into the future. Commercial benefits of research that will be realized in the near-term typically carry a lower risk. As the commercial payoff moves into the mid and long term, they develop a higher risk. With few exceptions, the highest risk production efficiency research is expected to yield commercially beneficial results in the mid and long term, with some providing benefits in all time frames. Near-term research activities are generally perceived to have lower overall risk.

Opportunities for collaborative research in production efficiency will most likely occur in the higher-payoff/higher-risk quadrant in Exhibit 3-4. Collaborations, whether among companies or between companies and the government, will tend to mitigate risk while providing large payoffs that can be shared by multiple companies. High-risk/high-payoff research activities are particularly well suited for government investment and participation. However, a research portfolio that combines near-, mid-, and long-term activities and a range of risks is highly desirable for a balanced R&D program.

4 Energy Efficiency

Each year the glass industry spends over $1.3 billion on the energy used in its manufacturing processes. Process energy accounts for a full 15 percent of the cost of glass products. In the face of growing challenges from foreign manufacturers and other materials, the glass industry seeks to reduce energy use as part of its broader effort to lower glass production costs. The industry believes the development of more energy-efficient manufacturing technologies will achieve significant energy savings and help to strengthen the competitiveness of glass products.

The Energy Efficiency Group evaluated glassmaking processes to identify the best opportunities for increasing energy efficiency while maintaining or improving product quality. Group members represented many major glass manufacturers, two national laboratories, and DOE's Office of Industrial Technologies. Three of the four segments of the glass industry were represented in the group, including flat, specialty, and container glass. Although there were no representatives from the fiberglass segment, many of the issues discussed are broadly applicable to all segments of the industry.

Energy Efficiency Work Group

Peter Angelini	Oak Ridge National Laboratory
Eugene Davis	Thomson Consumer Electronics
Laurence Feder	Institute of Gas Technology
James Fenstermacher	Owens-Brockway Glass Container
Dick Galusha	Corning Incorporated
Ramesh Jain	U.S. Department of Energy
Joe Keller	Idaho National Engineering and Environmental Laboratory
Jerry Kynick	St. George Crystal
Dan Lubelski	Pilkington Libbey-Owens-Ford
Fred Schaeffer	Libbey Glass
Ron Schroeder	Praxair, Inc.
James Shell	Techneglas, Inc.

Energy Efficiency Targets

In 1994, the glass industry consumed over 200 trillion Btu of process energy. Approximately 83 percent of this energy was in the form of natural gas, 13 percent in the form of electricity, and the remaining 4 percent in the form of residual and distillate fuel oil. Present glass manufacturing facilities clearly offer a large opportunity for energy savings. Whereas melting one ton of glass should theoretically require only about 2.2 million Btu, in practice it requires a minimum of twice that much because of a variety of losses and inefficiencies and the high quality of glass that is often required. One of the main goals set forth in the glass vision statement is to cut the gap between theoretical and actual energy requirements by half.

The melting/refining process is by far the most energy intensive of the primary glassmaking processes and is responsible for the majority of energy consumption. The Energy Efficiency Group examined the various melting and refining subprocesses and related areas to identify the most promising opportunities for increased energy efficiency. The resulting target areas (shown in Exhibit 4-1) are grouped within four categories: raw materials, melter technologies, post-melter processes, and process improvements.

Exhibit 4-1. Target Process Areas for Increased Energy Efficiency in the Glass Industry

Raw Materials	Melter Technologies	Post-Melter Processes	Process Improvements
Preheat batch and cullet materials Pre-treating (injecting in melter) Size of raw materials Wet materials vs. dry materials Compositions that require less energy	Air separation Melter Suspension melter (alternative melters) New melting technology Oxy-fired furnace	Annealing Forming Tempering Increase yield/decrease rejection rate of product Product quality Use of process heat Storage of product Transporting materials from facility to consumer	Additional plant costs: motors, air, process steam Facilities management Glass refining Reduce batch carry over Increase throughput

Technology Barriers

Barriers to more energy-efficient glassmaking are of two main types: technological and institutional. Technology barriers are commonly posed by immature technologies or scientifically unexplained processes that impede technical advancement. Removal of these barriers may require basic, pioneering research—the type that is particularly suited to collaborative efforts.

Surprisingly, the vast majority of barriers to more energy-efficient glassmaking center around institutional issues. These issues include corporate perceptions or philosophies, current investment strategies, and consumer opinions. These barriers may be as difficult and challenging as many technology problems. Efforts to overcome them may require diplomacy, psychology, political acumen, legal assistance, and determination.

Clearly, the industry will need to address both types of barriers to achieve its energy efficiency goal. As shown in Exhibit 4-2, technology barriers fall into two categories: knowledge of glassmaking processes and related technologies. Institutional barriers include: industry characteristics, funding constraints, consumer issues, and institutional issues.

Exhibit 4-2. Technology Barriers to Achieving Energy Efficiency Goals
(● = High Priority)

Knowledge of Glassmaking Processes	Related Technologies	Industry Characteristics	Funding Constraints	Consumer Issues	Institutional Issues
Need for new models and improvement of existing models - validating models ●● Non-Stokes refining methods ● Heat recovery (batch, cullet, preheaters) ● Lack of development of optimum raw material matching Lack of technologies for improving cullet quality Ways to use "everything but the squeal" Lack of use and development of closed-loop control systems Better heat transfer to the glass	Need for better refractories ●● High cost of industrial gas generation Non-existent enabling technologies	Glass Manufacturers mentality - lack of radical approaches - lack of industry cooperation - lack of interest in future technologies - risk aversion ● Too much single use/company thinking Poor perception of industry by new engineers Lack of interest in common research Lack of skilled workers on plant floor Proprietary thinking	High cost to develop and implement process technology ●●●●● Timing of rebuilds, long-lived assets Restrictive management criteria - economic modeling of new technologies - lack of financial returns Lack of capital to implement known technology Lack of R&D funds Lack of pilot-scale facilities	Lack of public knowledge of product specifications Lack of recycling rewards Lack of consumer education	No incentive for electric cost savings due to pricing International politics/ proprietary issues Non-uniform regulations (in US and internationally) Difficulty with ISO 9000 compliance Distrust of government intervention and participation

A limited understanding of some aspects of the glassmaking process is a key barrier to improved energy efficiency. This lack of understanding hampers efforts to improve existing models and develop new ones for optimizing glassmaking processes. Insufficient knowledge of the physical processes in glassmaking prevents the development of techniques for optimizing the use of raw materials.

Related technology barriers include processes and technologies that are vital to the production of glass, but which are also used in other industries. One of the most important of these barriers is the high cost of air separation to produce oxygen. An inexpensive source of pure oxygen would allow economical use of oxy-fuel firing in furnaces, thereby significantly decreasing NO_x emissions and specific melting costs. Another important concern is the performance and quality of existing refractory materials, which have a relatively short production life and are expensive to replace.

Some characteristics of the glass industry create barriers such as prevailing corporate investment philosophies and work force issues. For example, conservative business approaches in the glass industry constitute a key barrier to technology advancement. As a whole, the industry shies away from radical approaches to research and exhibits an aversion to high risk, regardless of potential payoff. The industry also has difficulty in recruiting new and talented workers who could support more progressive research and business opportunities.

Funding constraints within glass companies can be traced to the practice of spending a relatively small portion of funds on process research. The high cost and lack of capital to develop and implement technologies is a significant constraint on investments in energy efficiency. Many glass companies also do not recognize the benefits of changing and upgrading their existing processes due to the lengthy time requirements for rebuilds and the long life of capital assets.

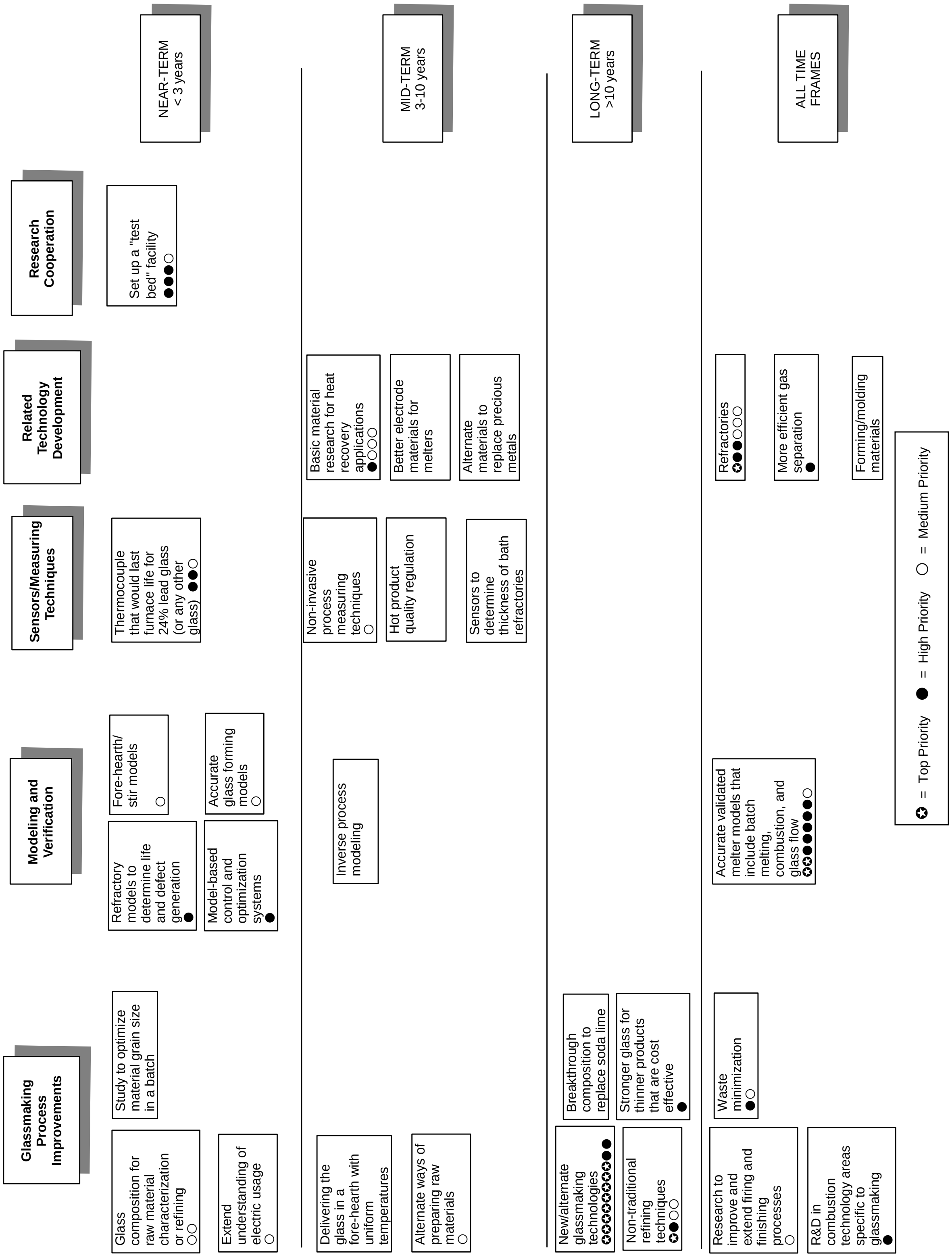
Some barriers to improving energy efficiency lie with the consumer. Consumers are generally unaware of the costs of producing glass from recycled materials as opposed to the cost of using raw material sources. Rewards for consumers who actively recycle are generally meager, resulting in low participation.

Institutional barriers include external factors, such as government regulations. For example, the non-uniformity of international and domestic regulations as well international politics and proprietary issues can create barriers to development of more efficient technologies. The need to comply with international (e.g., ISO 9000) and domestic standards can also limit the way technology is developed.

Research Needs

The technology research needed to overcome existing barriers to the industry's energy efficiency goals are shown in Exhibit 4-3. Research time frames that help to quantify the likelihood of when technologies will become commercially available are also displayed. The following definitions can be applied:

Exhibit 4-3. Major Research Needs for Energy Efficiency



- Near Term - technologies that will become commercially available in zero to three years
- Mid Term - technologies that will become available in three to ten years
- Long Term - technologies that will become available after more than ten years
- All Time Frames - research areas that will result in improved commercial technologies in zero to three years, but will continue to be major areas of research interest for the mid and long term

Research that corresponds to all time frames includes primarily projects that address the basic glassmaking processes. Research priorities such as combustion R&D and gas separation, more accurate melter models, and waste minimization are all fundamental research areas that will continue to be studied well into the next century. Near-term research needs generally focus on process control and optimization, as well as development of more accurate models for furnaces, fore-hearth delivery systems, and glass forming. Mid-term research needs have a fairly broad scope, such as the development of alternate materials to replace precious metals or development of better electrode materials for melters. This research could potentially benefit not only the glass industry, but other manufacturing areas that employ the catalytic and electrochemical processes. Lastly, the long-term needs includes research that would completely change the way glass is manufactured, such as alternate glassmaking technologies and non-traditional refining techniques.

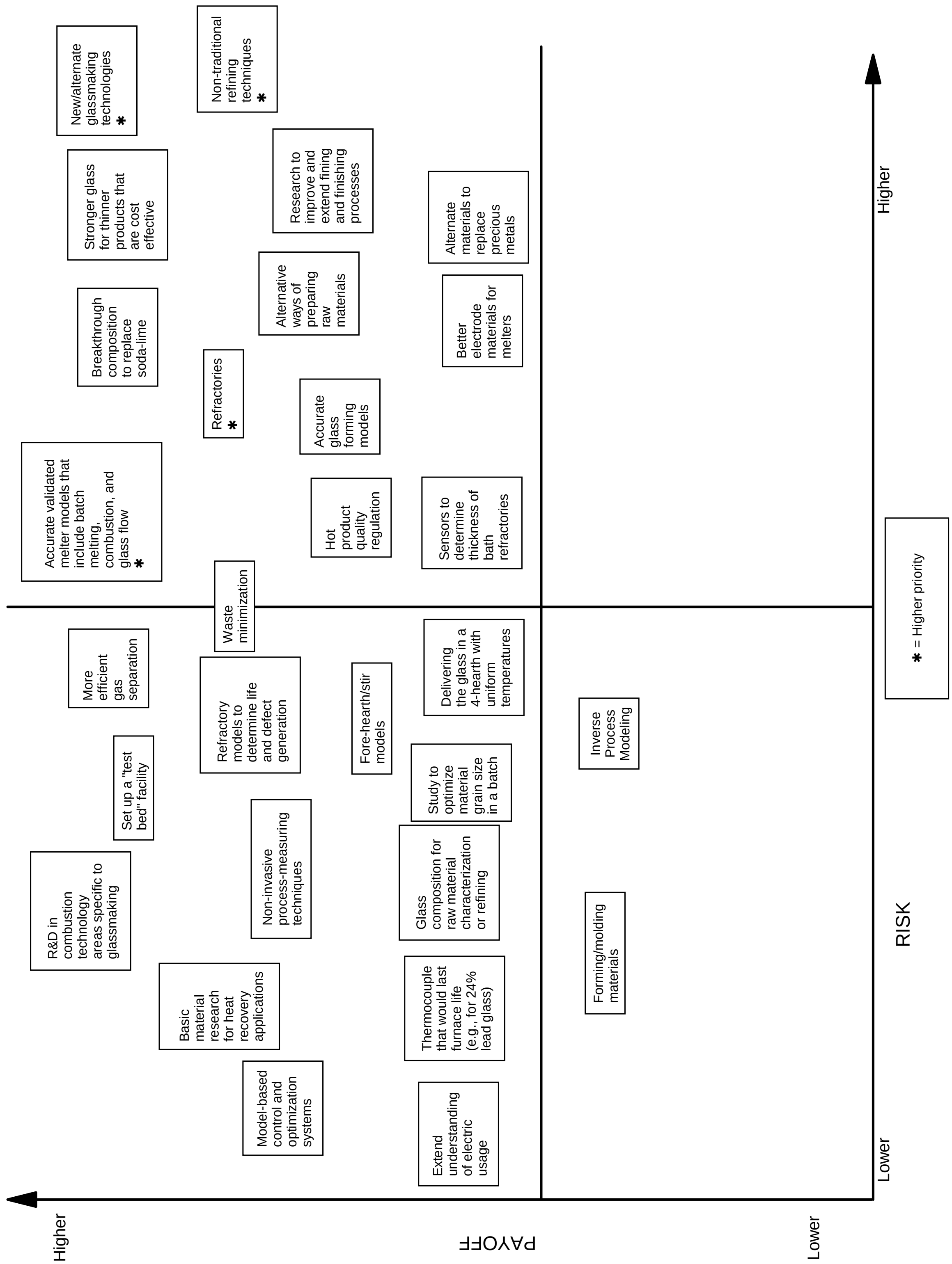
Payoff and Risk

The payoff versus risk chart, shown in Exhibit 4-4, further defines research priorities and benefits. Risk is defined as the probability that the research will result in a successful outcome; payoff is interpreted as a measure of commercial success such as increased glass shipments and profitability.

The chart is separated into four quadrants to help display relative areas of payoff and risk. The high-risk/low-payoff quadrant is empty, which is consistent with the research investment philosophy of most capital-intensive process industries. It is particularly true for the glass industry since many of the processes involved in glassmaking are mature and many of the low-payoff technologies have already been developed.

The majority of the research priorities fall into the high-payoff area of the chart. The high-payoff/high-risk quadrant contains many of the long-term research projects that were determined to be top and high priorities. The projects that fall into the category of long-term and high-risk research could be appropriate for government support through universities and industry. Several of these high-payoff projects that involve the development of improved models for glassmaking may benefit from a current research project that is being conducted at the Center for Glass Research with funding from OIT and participation by 17 glass manufacturers. The project is designed to produce a comprehensive and reliable database for eight important properties in glass forming melts. The final database will allow for full use of numerical simulation models by a broad cross-section of the glass industry.

Exhibit 4-4. Payoff vs. Risk for Energy Efficiency Research



5 Environmental Protection and Recycling

The Environmental Protection and Recycling Group focused on challenges and opportunities to reduce emissions and waste in the glass industry through leaner and cleaner production and processing as well as increased recycling. The group examined all facets of the industry's impact on the environment and assessed various approaches to environmental protection as part of its effort to identify and prioritize the industry's most important research and development needs in the area. Group members included representatives from all segments of the glass industry with the exception of containers. University researchers and the U.S. Department of Energy were also represented.

Environmental Protection and Recycling Work Group

Dr. Kanwal Bhatia	Ford Motor Company
Dr. Charles Drummond	Ohio State University
Mr. Kevin Fay	PPG Industries
Mr. Michael Greenman	Carr Lowrey
Mr. Theodore Johnson	U.S. Department of Energy
Mr. Otto Jones	CertainTeed
Mr. Kwaku Koram	Ford Motor Company
Mr. Jeff Lowry	Techneglas, Inc.
Mr. Philip Ross	Glass Industry Consulting

In many regards, the glass industry is relatively gentle on the environment. Its primary raw material is in abundant supply, and glass products are 100-percent recyclable. Relative to other industries, glass manufacturing processes are also fairly benign with the exception of NO_x emissions. Nevertheless, environmental issues are of growing concern to the industry. The reduction of undesirable wastes and emissions is a central component of the glass industry vision.

Over the past several decades, the industry has had to modify its processes and add equipment to comply with increased government restrictions on the emissions of NO_x, SO_x, and particulates. These changes have increased operating costs and reduced the availability of capital for other process improvements. In looking to the future, the industry expects a continuation of current trends toward more stringent pollution control regulations and higher waste disposal costs. There is also concern that future regulations may force the industry to control additional types of emissions or provide for the recycling or reuse of all products. By identifying and developing the technologies to address these concerns in a pro-active mode, the industry will be able to cost-effectively cope with future regulations. At the same time, the industry can take advantage of the broader economic benefits of cleaner technologies, including more efficient use of resources, improved worker health and safety, and enhanced public image.

Environmental Protection and Recycling Targets

To effectively plan research for improved environmental performance, the industry must first clarify its approach to the problems of environmental protection and recycling. A variety of strategies are currently in vogue, but may lead technology development in different directions. The group therefore explored the benefits of various approaches and outlined the components involved.

Environmental Protection encompasses health, safety, and ecology. An important aspect of environmental protection is *pollution prevention*—the redesign of processes and products to minimize the generation of waste and pollutant emissions. Pollution prevention is key to protecting the environment and is preferred to recycling. Glass industry spending on environmental projects continues to be primarily driven by reaction to state and federal regulations. Industry adoption of a more pro-active and unified pollution prevention approach to environmental protection may produce two key benefits: 1) lower production costs along with reduced emissions and 2) improved industry standing in the regulatory process, with greater opportunity to express the industry's viewpoint on the need for cost-effective, uniform, process-based emission targets.

Recycling of glass products is part of the larger concept known as *product stewardship*, which entails *cradle-to-grave* management of industry products. Although this is a commendable goal, the level of product stewardship that the glass industry as a whole can technically and/or economically assume is difficult to ascertain. Many European countries have implemented product/packaging recovery regulations without the technology and infrastructure necessary for industry to comply with them. While product stewardship may be a long-term goal, significant amounts of R&D are needed to make it a cost-effective reality. Current regulation is not an important driver of recycling in the United States, but this may change if landfill costs rise significantly or if regulatory agencies increase their attention to product stewardship issues. Life cycle analysis will be an important tool for evaluating the economics of the various recycling/product stewardship options for different segments of the glass industry.

As recycling options are considered, the industry should strive for the highest use of a material. Mixing materials from different industry segments or products results in downgrading the possible uses for the recycled material. The industry should therefore make its focus high-value recycling rather than "deferred landfilling" or "down-cycling."

Components of the challenges or opportunities in Environmental Protection and Recycling are listed in Exhibit 5-1.

Research to improve environmental protection and recycling will directly support five of the eight glass industry goals set forth in the vision statement (refer to Exhibit 2-1). Specifically, advances in the area of environ-mental protection will help to reduce not only process energy use but also air and water emissions (Goals 3 and 4). Advances in recycling and recovery will enable the industry to recycle almost all glass in the manufacturing process[1]; recover, recycle, and minimize all available post-consumer glass; and increase partnerships among suppliers and customers (Goals 2, 5, and 8, respectively). Since corollary (non-glass) materials are not directly addressed by the existing goals, Goal 2 should be expanded to include development of alternative uses for other by-products of glass manufacture (e.g., refractories).

Exhibit 5-1. Components of Environmental Protection and Recycling

Environmental Protection	Recycling
Air • NO_x • SO_x • CO_2 • VOCs (Volatile Organic Compounds) • Particulate • HAPs (Hazardous Air Pollutants) ***Water*** • Suspended Solids • Dissolved Solids • Thermal ***Solid*** • Hazardous • Non-Hazardous ***Ergonomics*** • In-Plant Temperature • Noise • Exposure to Substances	***Product*** • Pre-Consumer • Post-Consumer ***Manufacturing Waste*** • Raw Materials • Packaging • Lubrication • Paint & Decoration • Cleaning • Pollution Control Wastes • Spent Finishing Wastes ***Future Concerns*** • PM < 2.5 microns

Technology Barriers

To achieve environmental protection goals, the industry must overcome significant barriers associated with the glass melting process, the fundamental understanding of emissions, and regulations. As shown in Exhibit 5-2, most of these barriers come under the first two categories, which are closely related and contain some overlap. The glass industry also faces a number of obstacles to attaining its goals in the area of recycling or recovery and reuse.

Although progress toward cleaner processing is held back by the lack of sensors, measurement devices, instrumentation, and control technologies, the largest problem is the current melting and refining technology itself. Much of the current technology to produce glass is quite old and new technology is sorely needed. In the absence of a new furnace technology, better process

[1] Pertains only to products containing glass in such quantity that the average U.S. citizen consumes five pounds of glass or more in that product annually.

Exhibit 5-2. Technology Barriers to Achieving Environmental Protection and Recycling Goals
(● = High Priority)

Process	Fundamental Understanding of Emissions	Regulation	Recovery and Reuse
Lack of process control and instrumentation ● Theoretical limits of process efficiency Lack of selective process sensors Fuel efficiency and adaptability Inefficient heat recovery Modeling inadequacies for combustion High cost of oxygen production for oxy-fuel firing ● Production of by-products and contamination Broader compositional range Lack of <u>cost-effective</u> water treatment technology Technologies to control CO_2 emissions Lack of measurement technology for emissions (low-cost) Current melting and refining technology produces emissions ●	Fuels used (Energy) - link to process Lack of understanding of process mechanisms influencing particulates ● Lack of predictive emissions modeling tools Modeling inadequacies for combustion Composition - dependence of glass ● Nature of hazardous materials ● - carcinogenic - fibrous - air - etc. Chemistry of treating materials (lack of understanding) Lack of understanding of mold release chemistry/ emissions Measurement technology for emissions Understanding of melting and refining technology	Government regulations act to inhibit some technologies - minimum emission standards - state vs. federal (non-uniform) Lack of central industry group to interact with government Moving regulatory drivers Uneven enforcement of regulations Misguided regulations	Lack of tracking technology for recovery Composition-dependence of glass Separation and sorting of post-consumer waste ● - implications for other industries under the Industries of the Future initiative Economics of recycle ● Reverse distribution system--collection Technology for characterizing chemical and physical properties of glass Cost-effectiveness of beneficiation ● Industry and consumer attitudes to recycle vs. reuse

controls and instrumentation are required to reduce emissions. The oxy-fuel furnace, which presents the most cost-effective alternate technology for large, high-throughput furnaces, reduces NO_x emissions but has other operational drawbacks—primarily the high cost of oxygen production. The relatively narrow compositional range for glass also contributes to emissions problems. Other important process-related problems include inadequate combustion models, inefficient heat recovery, and inefficient and nonflexible fuel use.

The industry would be better equipped to reduce emissions if it had a stronger understanding of the formation and fate of emissions in current melting and refining technologies. A better understanding of the fundamental process mechanisms and chemistries is needed before these technologies can be significantly changed to improve their environmental performance. In this regard, three problems stand out. First, a lack of understanding of the process mechanisms influencing the formation of particulates hinders development of a cleaner system. Second, the industry has an inadequate understanding of the hazardous materials created, which makes it difficult to avoid their production or develop better treatment methods. Third, a better understanding of the composition-dependence of glass could facilitate environmental protection efforts. Other aspects of this fundamental problem include the lack of predictive emissions modeling tools and existing technology-based restrictions on the types of fuels that can be used for processing.

Regulations often set forth inflexible emissions standards at levels that may be technically feasible but not economically feasible. Expenditures used to meet these regulations may inhibit industry's ability to invest in the development of new technologies or processes that may be more effective or cost-efficient in controlling emissions in the long run. A further problem is the lack of uniformity among state and federal regulations, especially as more and more states set their own standards. Variations in regulations from place to place and over time make it difficult for manufacturers to develop cohesive pollution prevention and control strategies. The industry has no central organization or coordinated strategy to represent industry interests in the regulatory process; without this representation, prospects for improving the industry's regulatory climate are substantially diminished.

Although roughly 37 percent of all glass containers were recycled in 1994, the recovery and reuse of glass products could be significantly expanded with the development of more effective technologies or processes for sorting and separating post-consumer waste. Currently, about 67 percent of all cullet is landfilled or stockpiled. The industry needs technologies that can reliably identify and eliminate non-glass materials from the stream and efficiently sort glass by color. Since many industries have an interest in recycling, a cost-efficient approach may be to work with other industries in developing a sorting and separation technology that can be used on all kinds of post-consumer waste. Other important barriers to increased recycling are economic: the industry needs to improve the cost-effectiveness of beneficiation and otherwise strengthen economic incentives for recovering and reusing post-consumer glass.

Research Needs

A wide range of research and development is needed to overcome existing barriers to achieving the industry's environmental protection and recycling goals. Exhibit 5-3 shows the R&D needs by subject category and distributed by the time frame (near, mid, or long) in which commercial results are expected from the research.

Environmental Protection

Environmental protection goals are best achieved through research and development in emissions characterization and control, alternative materials, and oxy-fuel firing. Within the area of emissions characterization and control, accurate, predictive emissions modeling tools are considered to be the most important research need. Although some predictive models exist, they require further refinement and validation as well as calibration for use with glass furnaces. More reliable modeling tools are a necessary prerequisite for another high-priority research need—the development of integrated control systems to link production with emissions. These systems would enable plant operators to adjust production parameters in response to real-time analysis of emissions. Cooperative research can satisfy both of these high-priority needs within 3 to 10 years.

An important pre-cursor to these high-priority projects is the development and validation of coupled combustion and glass melt models. This near-term research will build on modeling efforts already underway and will lay the ground work for additional modeling and control tools. More data is also needed to support process modeling and control, especially quantitative data on emissions (e.g., volatiles and particulates) relative to process variables. To collect this data, advanced, low-cost sensors are needed to continuously monitor in-process and post-process emissions.

A fundamental understanding of the mechanisms involved in the formation of emissions from glass and raw materials is also a high priority in the near term. This understanding is critical to support process modeling and the development of advanced sensors and abatement technology. Improved emission abatement technologies are needed to effectively control the release of emissions from existing melting furnaces at a reasonable cost. As an example, researchers could develop techniques to coalesce particles in emissions streams to facilitate treatment and disposal (or enable other applications). Once researchers understand emissions mechanisms and how they are affected by process variables, it may also be possible to develop alternative materials and processes for the use of hazardous raw materials. For example, the hazardous material selenium is currently released from the raw materials during processing. A substitute material and/or some alteration to processing may enable the industry to avoid this costly problem.

Expanded knowledge of emissions mechanisms will support a more general melting/process need for durable, high-temperature sensors to measure flow, temperature, and gas composition (as well as identification of new sensing techniques for in-process measurement of emissions.) Such sensors will provide real-time feedback to processing operations to minimize undesirable emissions.

In the area of alternative materials, the industry's most critical task is to develop and evaluate alternative refractories for melting systems. In particular, the industry needs durable, corrosion-resistant refractories for use in oxy-fuel furnaces. In the near term, this research

Exhibit 5-3. Major Research Needs for Environmental Protection and Recycling

	Emissions Characterization Control	Alternative Materials	Melting/Process Developments	Melting/Process Developments: Oxy-Fuel	Post-Market Processes
NEAR-TERM < 3 years	Quantify emissions relative to process variables Identify emission mechanisms from glass and raw materials ✪ Develop sensors for continuous, low-cost monitoring of emissions (post-process) ✪○○	Develop and evaluate refractories for melting systems ✪●●○	Develop and validate coupled combustion and glass melt models ●	Quantify volatiles and particulate emissions	
NEAR/MID-TERM	Better understanding of hazardous metal oxides and methods of treating ○ Develop better understanding of batch melting mechanisms			Develop technologies for utilization of waste heat (e.g., cogeneration) ●	
MID-TERM 3-10 years	Develop predictive emission modeling tools ✪✪● Develop techniques to correlate opacity to mass emissions Learn the chemistry of what happens during swabbing Develop integrated control systems to link production with emissions ✪● Develop emission abatement techniques for existing melting (e.g., to coalesce particles) ●●○	Develop alternatives to swabbing (new materials?) Develop low-emission coating technologies Develop alternative materials and processes for use of hazardous raw materials ○	Develop durable high-temperature sensors for flow, temperature, and gas composition ●●○ Develop lower-noise cooling methods	Develop more efficient, lower-cost oxygen production method ✪✪ Significant cost reductions (breakthrough process!)	Develop cost-effective separation and sorting technologies for post-consumer glass ●●●●○○ Develop new vitrification processes and/or products ○ Investigate cost-effective beneficiation for cullet ● Overcome barriers that preclude recycle of specialty glass (e.g., windshields) ○
MID/LONG-TERM	Identify new sensing techniques for in-process measurement of emissions ●● Measure the composition of swabbing smoke		Develop better understanding of physics of glass refining ○○○ Find non-polluting alternative refining mechanisms ○○	Evaluate and optimize refining mechanism	
LONG-TERM > 10 years			Develop fusion-based melting technologies ○○ Develop instantaneous melting system ✪	Develop new heating mechanisms to economically melt glass <u>without</u> noxious emissions ●●	

✪ = Top Priority ● = High Priority ○ = Medium Priority

should produce alternative refractory materials that, at the end of their useful life, will qualify as non-hazardous material (or waste) for disposal purposes. Ideally, they may even be converted to some other use.

The development of longer-life mold coatings are another way to reduce undesirable emissions. Periodically, glass molds must be coated with a release agent. This swabbing process generates large quantities of smoke containing particulate matter and volatile organic compounds. The development of more durable coatings would reduce the frequency of swabbing. Alternatively, improved mold materials that do not require frequent swabbing would also lower pollutant emissions.

Within the category of melting and process developments, the highest priority need is in oxy-fuel firing. In particular, the industry needs a more efficient, lower-cost method for producing pure oxygen for use in oxy-fuel furnaces. The high cost of oxygen production is currently a significant deterrent to the wider adoption of this cleaner and more efficient technology. The industry needs a breakthrough process that will enable significant cost reductions. This research could be expected to yield results within 3 to 10 years.

All of the aforementioned research will both contribute to and be supported by an improved understanding of the physics of glass refining. This understanding will be important in evaluating and optimizing the refining mechanism and in finding a non-polluting alternative to current refining techniques.

In the long term, collaborative government-industry research efforts could enable the development of an instantaneous glass melting system. With funding from the National Institute of Standards and Technology (NIST), the Gas Research Institute and Vortec began work on an instantaneous melting system, but work was suspended when NIST funding ran out. If additional funding were available, this important research effort could be resumed. The development of more efficient, non-polluting glass melting and refining systems is a key long-term goal for the industry. Fusion-based electric power systems, though only a technology dream at present, could revolutionize the glass manufacturing process and dramatically reduce system emissions.

Recycling

Research projects that contribute to recycling goals can be characterized as post-market processes (see Exhibit 5-3). The industry's top need is a *cost-effective* technology for sorting and separating post-consumer glass. The industry could develop this technology in partnership with other industries that have a vested interest in effective post-consumer material recovery processes (including iron and steel, aluminum, paper, plastic, etc.). By reliably and cost-effectively creating uncontaminated waste streams of same-color cullet, this technology would make it possible for post-consumer glass to be returned to its highest value use. At the same time, the glass industry could reduce its use of raw materials and avoid landfilling. Since cullet can be melted at lower temperatures than raw materials, substantial production cost savings could be achieved as well. Recycling can lower energy costs by \$2 to \$5 per ton (compared to using all virgin raw materials), depending upon the industry segment.

Research on the cost-effective beneficiation of cullet is needed to develop new markets and higher-value uses for cullet. By removing impurities from the glass waste stream, this technology could serve as an intermediary technology until an integrated, inter-industry sorting technology can be developed, or it might be incorporated into the broader technology. Other important research needs include development of new vitrification processes (possibly using cullet as a raw material) and technologies for recycling various types of specialty glass, such as windshields. As shown in Exhibit 5-3, all research identified in the area of post-market processes can be expected to result in commercial application or products within 3 to 10 years.

Payoff and Risk

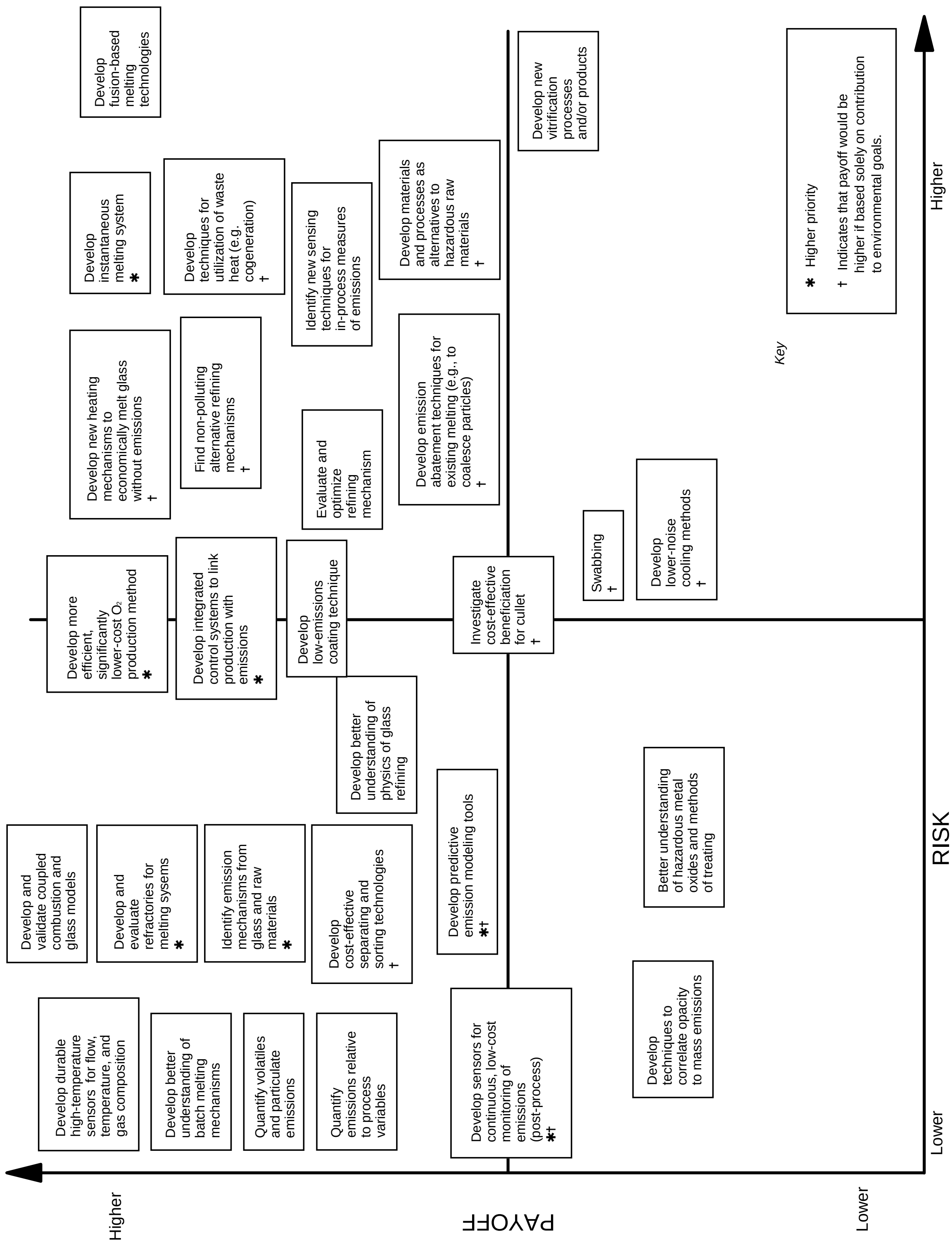
The potential payoffs and risks associated with these important research needs are shown in Exhibit 5-4. The identified needs are situated *relative to each other* along a continuum of lower to higher risk and lower to higher payoff. For the Environmental Protection and Recycling area, payoff can be considered as 1) the potential for increased glass product shipments and/or increased profitability resulting from the research or, 2) the potential contribution toward achieving the environmental goals established by the industry, regardless of financial payoff. Exhibit 5-4 shows the arrangement of the research needs with regard to the first definition of payoff. If the second definition of payoff is applied, then the research needs marked with a dagger (†) would rise significantly on the payoff scale.

The higher-payoff, lower-risk research needs are clustered in the upper left quadrant of the matrix. Many of these needs are associated with the development of sensors and modeling systems for controlling or eliminating emissions from existing glass melting systems and production processes. The highest-payoff, lowest-risk research is to develop durable, high-temperature sensors for controlling process flow, temperature, and gas composition. These sensors would be used in existing systems and processes to measure and control process variables of known interest to glass manufacturers. Developing sensors for continuous, low-cost monitoring of post-process emissions is a lower-payoff activity from the standpoint of economic payoff. However, if payoff is calculated on the basis of contribution to environmental goals alone, then this research need will produce a payoff equal to that of the in-process sensors. The similar (but higher-risk) research need to identify new sensing techniques for in-process measures of emissions, would be addressed by the development of conceptually new sensing technologies that can be used to control new glass processes and/or measure potentially important process variables not yet considered in the glass manufacturing process.

One of the highest priority recycling needs—developing cost-effective separating and sorting technologies—is considered to be higher payoff and lower risk. Again, the payoff of this research need would be substantially higher if environmental goals alone were considered. Risk is lower because this is a cross-industry research need and is an area in which substantial gains can be made by coordinating with and building on similar research being conducted by and for other primary and secondary manufacturing industries (e.g., steel, iron, aluminum, paper, automotive, electronic equipment, etc.)

Some enabling research can be characterized as higher payoff and lower risk. Research such as developing validated, coupled combustion and glass models; developing and evaluating

Exhibit 5-4. Payoff vs. Risk for Environmental Protection and Recycling



refractories; better understanding batch melting process; and quantifying process emissions are precursors to achieving some of the industry's broader technical goals. These activities have the potential for producing a high payoff while presenting a low risk that the results of the research will not be successfully applied. Since some work in these areas is already in progress, it narrows the scope of remaining work to be done. In the case of developing validated, coupled combustion and glass melt models, there are a number of existing models that could be or have been applied to the glass industry. However, these models must be further developed, refined, and validated in glass manufacturing systems before they can be really useful.

6 Innovative Uses

The Innovative Uses Group examined potential new markets for glass products as well as the expansion of existing glass markets. Group members represented companies from all segments of the glass industry, including specialty glass, glass containers, flat glass, and fiberglass products. Group members also included the director of a university glass research program, a national laboratory scientist, and a representative from a government program that supports research on new glass technology.

Innovative Uses Work Group

Rolf Butters	U.S. Department of Energy
Noshir Havewala	Corning Incorporated
Hann-Sheng Huang	Argonne National Laboratory
Tom Huff	Owens-Corning
Bill LaCourse	Center for Glass Research
Alex Marker	Schott Glass Technologies, Inc.
Phil Newell	Guardian Industries Corp.
Fred Quan	Corning Incorporated

Glass is found in a myriad of products ranging from everyday tableware to highly sophisticated fiber-optic communication systems. Glass products are well-established in a number of key markets, including insulation, lighting, windows, containers, and consumer electronics, to name a few. The unique properties of glass (e.g., transparency, chemical durability, optical qualities, recyclability) and the fact that it is produced from abundant natural resources (essentially sand and common minerals) are behind the success of glass products. Despite these advantages, glass products face significant competitive pressures from products made of alternate materials (plastic, aluminum). Increasing competition from glass manufacturers in other countries, where labor, liability, and environmental costs are lower, also poses a considerable future challenge for American glass products (flat, specialty glass, and reinforcing fiberglass are most affected).

To meet these challenges, the glass industry will need to broaden the use of glass in existing markets and support research to create completely new and innovative uses for glass. New markets could potentially emerge in telecommunications, medicine, electronics, waste treatment, and infrastructure. While some dramatic breakthroughs have occurred in the use of glass in the last decade (fiber optics, photonics, fiber-reinforced composites, glass for storing radioactive waste), the unique attributes of glass have not been fully explored. To do so will potentially require the investigation of new glass compositions, a better understanding of glass properties and interactions, and the modification and improvement of essential glass-making processes. Furthermore, new glass products will need to be cost-competitive to successfully penetrate emerging markets. A critical challenge for glass manufacturers in developing new products will be increasing profit margins along with expanding markets.

Innovative Uses Targets

The glass industry's vision document, *Glass: A Clear Vision for a Bright Future*, recognizes that the "development of innovative uses of glass is a linchpin of the industry's future." Accordingly, **creating innovative products that broaden the marketplace** is one of the specific goals the industry should strive toward to achieve future robustness. The Innovative Uses Subcommittee had previously identified a number of broad product areas that offer significant future market potential. The Innovative Uses Group further expanded and divided these categories into more specific areas.

The potential for innovative new uses of glass exists across a wide spectrum of consumer and industrial applications. The products shown in Exhibit 6-1 are merely representative of each product category; they do not reflect the complete list of potential products.

Exhibit 6-1. Industry-Wide Product Categories Essential to Broadening the Market for Glass Products

- Sun Power (solar lens and mirrors, photovoltaics)
- Structural Applications (acoustical materials, thermal insulation, fireproof materials, foam glass roofing, flooring)
- Infrastructure (roadbeds, bridge materials, reinforced concrete)
- Electrical/Electronic Products (flat panel displays, new laser materials)
- High Strength Glass/Other Special Properties (flexible/deformable glass, unbreakable glass, lightweight glass, self-healing glass)
- Biological/Medical Devices (glass/bone implants, controlled release products)
- Environmental/Waste Treatment (encapsulation of waste, recycling)
- Composites (fiberglass reinforced composites, glass-polymer composites)
- Optical/Photonics (opto-electronics, optical security devices)
- Agriculture/Farming (controlled release fertilizers)

Although glass is already active in a number of these markets, there are opportunities for entirely new uses of glass. The use of glass for hazardous waste encapsulation, foam glass roofing, and roadbed aggregate, for example, represent innovative new ways to utilize glass. In some product areas small markets for glass products already exist and could expand significantly over the long term (glass flooring, architectural glass, acoustic materials). In other categories, improvements in glass properties or reductions in product cost could open potentially large new markets (lightweight glass, fiber-reinforced concrete, and flat panel displays).

Technology Barriers

A number of technology barriers inhibit the greater utilization of glass. Some barriers are related to the physical, chemical, and aesthetic requirements of the finished product. Others concern the current limitations of existing glassmaking processes. Perhaps most prevalent are the lack of basic understanding of the properties of glass at the molecular level, its interactions with other materials and reactions to physical phenomena, and the chemical changes taking place during melting, refining, and forming of the glass. For example, potentially large and lucrative markets for fiber-reinforced concrete have not been realized because alkali-resistant fibers are not currently available. These major issues correspond to processing, materials, medical, structural, chemical, and environmental barriers (see Exhibit 6-2).

Processing issues are dominated by a number of barriers related to inadequate on-line measurement and control of critical parameters (e.g., glass profile measurement, distortion measurement, flow characteristics, temperature gradients) and processes in general, particularly melting and refining. Several barriers are also related to the lack of technologies for specific product-related processing needs, such as the need for economical and effective on-line coating processes and the lack of processing technology available for nitrided or carbided glasses. Although not major issues, energy efficiency in general, as well as the availability of flexible, cheap power supplies, are also underlying barriers.

Materials-related technology barriers primarily concern specific property requirements that are critical to expanding the use of glass (e.g., high strength, durability, high modulus, high temperature). Priority barriers include a lack of understanding of surface structure, chemistry, and interactions, all of which are critical to pursuing many new applications of glass. The availability and purity of raw materials is also a limiting factor in the production of new glass products. The availability of good refractories is an important general issue for all glass products. The lack of inexpensive metal refractories is considered to be a particularly important and limiting factor for new specialty glass products.

In the area of medical and biomedical devices, the difficult regulatory approval process and associated product liability issues are the main constraints on the development of these high-value products. Similar liability issues have been raised in the use of fiber-reinforced concrete for bridge decks. Companies currently involved in developing these devices are often small, start-up firms that simply go under if the regulatory and liability concerns cannot be addressed. Recent product liability issues (e.g., silicone implants) and their huge associated costs have deterred many larger firms from investing in the long-term, high-risk R&D necessary to develop products for this market.

Structural barriers are those related primarily to the innovative use of glass in new structural and infrastructural applications (e.g., buildings, bridges). A major concern is the lack of adequate technology for transporting very large glass objects without damaging the surface (protection down to the micro level could be important). For example, micro damage can reduce the tensile strength of fiberglass by 40 percent. There is also a need for accelerated lifetime analysis. Data is needed to develop adequate protocols or models that will aid in the

Exhibit 6-2. Technology Barriers to Achieving Innovative Uses Goals

(● = High Priority)

Processing	Materials	Medical	Structural	Chemical	Environment
Poor data on melting/forming processes ●	Lack of understanding of surface structure, surface chemistry, and surface interactions ●	Highly prohibitive and costly regulatory and liability issues ●	Lack of adequate protection for large glass surfaces in transport (down to micron level)	Lack of substitutes for toxic glass components	Adverse public perception of products made from waste
Suboptimal measurement and control of processes ●	Little or no data on non-linear properties of glasses		Limited/no data for accelerated life time analysis	Need to expand limits of chemical durability	Lack of acceptance for using vitrified glass to encapsulate waste
Limited technology for glass profile measurement in high temperature regimes ●	Lack of high modulus, high temperature glass		Potential liability issues	Few or no substitutes for SO_2 lubricant	Limited innovative uses for products made from wastes
Lack of adequate distortion measurement technology	Less than optimal durability of low-temperature glass			Inadequate control of purity of synthetic raw materials	Lack of good alternatives for current water treatment processes
Poor understanding and control of temperature gradients during forming	Inadequate or uncertain availability and purity of raw materials ●				
Lack of a non-intrusive flow characteristic measurement device	Lack of availability of high strength glass ●				
Lack of a cheap/reliable electric power source integrated with glass plant	Refractories with suboptimal properties				
No renewable-energy fueled power source for melting	High cost of refractory metals used in specialty applications				
Suboptimal heat transfer in the glass furnace	Inability to match refractory index of epoxy with glass				
Poor efficiency of melting equipment	Lack of economical technology for reuse of glass fibers				
Limited processes for on-line coatings	Temperature limitations of glass composites ●				
Lack of processes for nitrided/carbided glasses	Limited new inorganic/organic composites (other than sol-gel)				
No cheap way to produce large area controlled porosity glass					

lifetime analysis of new glass products that are expected to perform over a very long life (e.g., 50-year bridge spans).

In the area of chemical requirements, the toxicity of components currently used in glass products is a potentially serious barrier in view of increasing environmental concerns. Another environmental/chemical issue is the use of SO_2 as a lubricant and its future regulation. Substitutes may be needed as increasing regulatory constraints are imposed. The inability to effectively measure or control the purity of synthetic raw materials could also limit the development of some new products. While chemical durability is one of the major attributes of glass, it is an area that could be improved for some new applications.

Environmentally related barriers concern the use of glass processing wastes and, alternatively, the use of glass as a waste treatment option. Public perception of products made from recycled wastes in general is a barrier (particularly hazardous wastes), and improved public awareness is needed to elevate product acceptance. The public's poor perception of products from waste contributes to a lack of motivation or interest in coming up with new ideas for glass products made from wastes. Other important barriers in the area of environment include the lack of economical and efficient alternatives for water treatment.

Research Needs

Research that is needed to overcome technology barriers falls into three major areas: products, processing, and analysis. Product research addresses specific product requirements as well as the processing needs unique to the product (see Exhibit 6-3). Product categories include: optical/photonics, electrical/electronics, sun power, composites, structural, high strength/other properties, farming, and environmental/waste treatment. Processing research focuses on more general processing needs that would enable the development of a broad range of products. Analysis research emphasizes the understanding of glass properties and associated measurement and modeling.

Product-Specific Research Needs

Optical/photonic applications for glass include basic research into the reaction of glass materials with radiation as well as more applied research into new glass materials. Comprehensive development is needed in the area of non-oxide glasses, with efforts ranging from investigation of raw material compositions through final processing and forming techniques. The development of ultraviolet- and infrared-transparent materials is also considered important.

To promote the use of glass in electrical/electronic products, research is needed to develop industrial scale cleaning technologies. This is related to the large-scale development of flat panel displays, for which a large market is technically available now.

Research in the area of sun or solar power is needed to improve the efficiency, usability, and cost of photovoltaic cells. While such research may not be pursued by glass companies, it will be critical to promoting the use of glass products in solar-powered systems. Continued

Exhibit 6-3. Major Research Needs for Innovative Uses

	Optical/Photonic	Electrical/Electronic	Sun Power	Composites
NEAR-TERM < 3 years			Photovoltaic (pv) cells for automotive windshields (to provide heating and cooling) ● Develop improved solar lens and mirrors ● Develop systems to integrate LiBr absorption heat pumps with pv cells ○ Research to increase the energy conversion efficiency and lower the cost of pv cells	
NEAR/MID-TERM	Develop ultraviolet and infrared transparent materials Research to increase understanding of glass material reactions with radiation	Industrial scale cleaning technology Development of flat panel displays ○		
MID-TERM 3-10 years	Research and development of non-oxide glasses (from raw materials through processing techniques) ○			Advances in fibers to enable technical feasibility of fiber-reinforced concrete (need for alkali-resistant glass) Develop processes for forming glass ceramic composites (irregular shapes) Develop cheaper sol-gel processing
LONG-TERM > 10 years				
ALL TIME FRAMES				

✪ = Top Priority ● = High Priority ○ = Medium Priority

Exhibit 6-3. Major Research Needs for Innovative Uses (cont.)

Time Frame	Structural	High Strength/Other Properties	Farming	Environment/Waste
NEAR-TERM < 3 years	Design products specifically for enhancing the environment (eco-products); Develop structural uses with only compressive loads	Develop high-speed coatings for organic and inorganic materials; Improve thermal tempering processes for thin/complex shapes	Explore use of broken glass to deter rodents (tree farming)	Promote uses for vitrified glass as waste treatment option
NEAR/MID-TERM	Develop smarter "smart" windows	Optimize chemical processing for high strength ●		
MID-TERM 3-10 years		Pursue entirely new concepts for imparting high strength		Life cycle analysis for selected glass products (CRTs)
LONG-TERM > 10 years				
ALL TIME FRAMES				Research to investigate laser destruction of NO_x ○

✪ = Top Priority ● = High Priority ○ = Medium Priority

Exhibit 6-3. Major Research Needs for Innovative Uses (cont.)

	Melting/Fabrication/Forming Processes	Analysis
NEAR-TERM < 3 years	Develop cheaper processing techniques for optical glasses	Adapt advanced light sources for measurement of process variables ○
NEAR/MID-TERM	Modify existing profile instrumentation to handle the high temperature tank environment Develop on-site electrochemical power generation sources for glass plants Optimize furnace designs through integrated computer aided design and new measurement techniques for critical furnace variables	Develop techniques for real time composite sensing
MID-TERM 3-10 years	Explore use of microwaves and ultrasonic waves for control of glass shape and other critical process variables (e.g., in refining) ●●●○○	Develop a protocol or model for accelerated life time analysis for long-life products (e.g., infrastructure) ○ Research to characterize/model chemical reactions during melting Research to increase understanding/model surface modifications, surface interactions, surface chemistry, and reactions of the glass interface with other materials ✪✪✪✪●●
MID/LONG-TERM	Develop cheap, high temperature refractory metals ●●○ Develop refractories that do not introduce defects ●●●	Investigate atomic and bulk glass property relationships ● Research to increase understanding/model non-Newtonian glass flow (high shear rate) Develop electro-chemical techniques to sense the ionic content of glass ●○
LONG-TERM > 10 years		Glass making process integration through models, sensors, and feedback loops ○○
ALL TIME FRAMES	Design new closed loop systems that promote recycling/ reuse of glass processing wastes Develop advanced concepts for melting Develop more effective sensors for measurement and control of critical parameters - temperature - viscosity - NO_x - redox reactions - gas velocity - colorants - waste separation ✪✪✪●○○○	

✪ = Top Priority ● = High Priority ○ = Medium Priority

improvement of solar lens and mirrors is also considered to be an important area for expanded market penetration of solar systems. Markets for these products will be affected by future fossil energy markets and prices.

Research to support development of innovative new composites should focus mostly on processing techniques. An important area is enabling research to permit the use of fibers in fiber-reinforced concrete (fibers are currently not alkali-resistant and degrade after contact with the concrete components). Processes for forming glass ceramic composites (irregular shapes) and cheaper sol-processing are also included as important to the development of new composite products.

Research is needed for structural uses of glass including the design of new products with unique attributes geared specifically toward environmental protection (eco-products), either directly or through waste utilization. This is an important area with very broad market potential. Another important area with the potential to expand existing markets is the development of "smarter," less expensive smart windows. One innovative idea concerns the design of glass structural products using only compressive loads. Numerous ideas for these products could be generated through university competitions or some similar mechanism.

Glass products with high strength or other special properties are particularly important for new product development. A broad research effort could investigate entirely new avenues for imparting strength to glass. Chemical processing is another possible approach for optimizing glass strength.

The consensus of the Innovative Uses Group was that the environmental applications of glass are particularly under-utilized, primarily because of public perceptions of recycled waste products in general. Promotional activities of some kind may be needed to increase acceptance of using vitrified glass as a waste treatment option. Another important research need in the environmental area is some life cycle analysis of glass products to promote "design for recycle" philosophies. Fundamental research could be pursued (possibly through the national laboratories) to investigate the laser destruction of NO_x — a potentially useful new application in glass melting furnaces.

Processing Research Needs

Much of the research needed for glass processing focuses on the melting and refining of glass. The highest priority is in the development of more effective sensors for measuring and controlling parameters that are critical for optimizing the melting/refining process. Research could explore innovative ways to sense and control glass shape/profile, including the use of microwaves and ultrasonic waves. Refractories are another area in which research is needed to enable the design and development of innovative new glass products, particularly in the area of refractory metals, which are currently very expensive. In general, advanced, innovative concepts for melting glass will be needed to promote and enhance the viability of new product development and enhance existing production. Supporting research includes optimization of furnace designs through integrated computer simulation. Research to develop an inexpensive, reliable, on-site source for electricity generation, although not specifically within the realm of the glass industry, is one way to promote the use of electrical melting processes that might be more cost-effective for some products.

Analysis Research Needs

Analysis of the physical, chemical, and mechanical glass properties is critical to the successful development of most new glass products. A top priority is increasing knowledge and understanding of what occurs at the glass surface, including surface modifications, surface interactions, surface chemistry and reactions of the glass interface with other materials. A lack of understanding in this area (and lack of funds to pursue this knowledge) prohibits companies from pursuing the use of glass for a number of applications. Other areas where knowledge of glass properties is lacking include the oxidation state of the glass melt, chemical reactions during melting, atomic and bulk glass property relationships, and glass flow.

Closely related to the understanding of glass properties is the ability to measure or sense glass properties during the glassmaking process. Research in this area should emphasize the need for real-time composite sensing capability, innovative techniques such as light sources for measuring glass properties during processing, and process integration through the use of models, sensors, and feedback loops. The study of the electrochemistry of glass and other materials at high temperatures may provide one approach to new sensing capabilities. The need for ways to model the lifetime of very long-life products (e.g., bridge or road components) is an essential requirement for the use of glass in new structural applications.

A number of research needs in the high risk category will require fundamental or exploratory efforts. Many of these (e.g., development of more effective sensors, understanding and modeling of surface chemistry and interactions, and entirely new concepts for imparting strength to glass) may be of a scope that is appropriate for joint government-industry support. Some are considered to have very high payoff, indicating that a successful R&D effort could provide benefits at the national level as well as to individual glass companies and the entire glass industry.

Segment-Specific Priorities

Representatives from each of the four industry segments prioritized research areas that are most important to their individual segments. All segments cited inadequate measurement and control of process variables as a key problem. Other priorities for individual segments include:

- *Flat glass* - Refractory-related problems (primarily defects imparted to the glass from refractories) are the most critical research issue for this segment.
- *Container glass* - Controlling temperatures and maintaining homogeneous temperatures at the gob are a major problem for container glass manufacturers. Refractory-related defects also create many problems for this segment.
- *Glass fiber* - Understanding phenomenon at the glass surface (chemistry, interactions) is the major research need for glass fiber manufacturers.
- *Specialty glass* - Surface phenomenon and refractories are major issues for specialty glass manufacturers, particularly the need for inexpensive alternatives to precious metals and

metal refractories. The disposal of used refractories (which are a hazardous waste) is also an increasing and costly problem for all segments of the glass industry. Understanding radiative properties (infrared, ultraviolet) will be very important for some new product development.

Time frames for research are organized according to the various research categories for products, processes, and analysis in Exhibit 6-3. Near term is defined as 0 to 3 years; mid term is defined as between 3 and 10 years; and long term is defined as greater than 10 years. Sorting research according to these categories is difficult, as much of the research overlaps several time frames. Compromise categories accommodate research needs for which time frames are more uncertain. One such category, titled "near-mid-long term," includes research that may have results in the near term, but is also expected to continue throughout the mid- and long-terms.

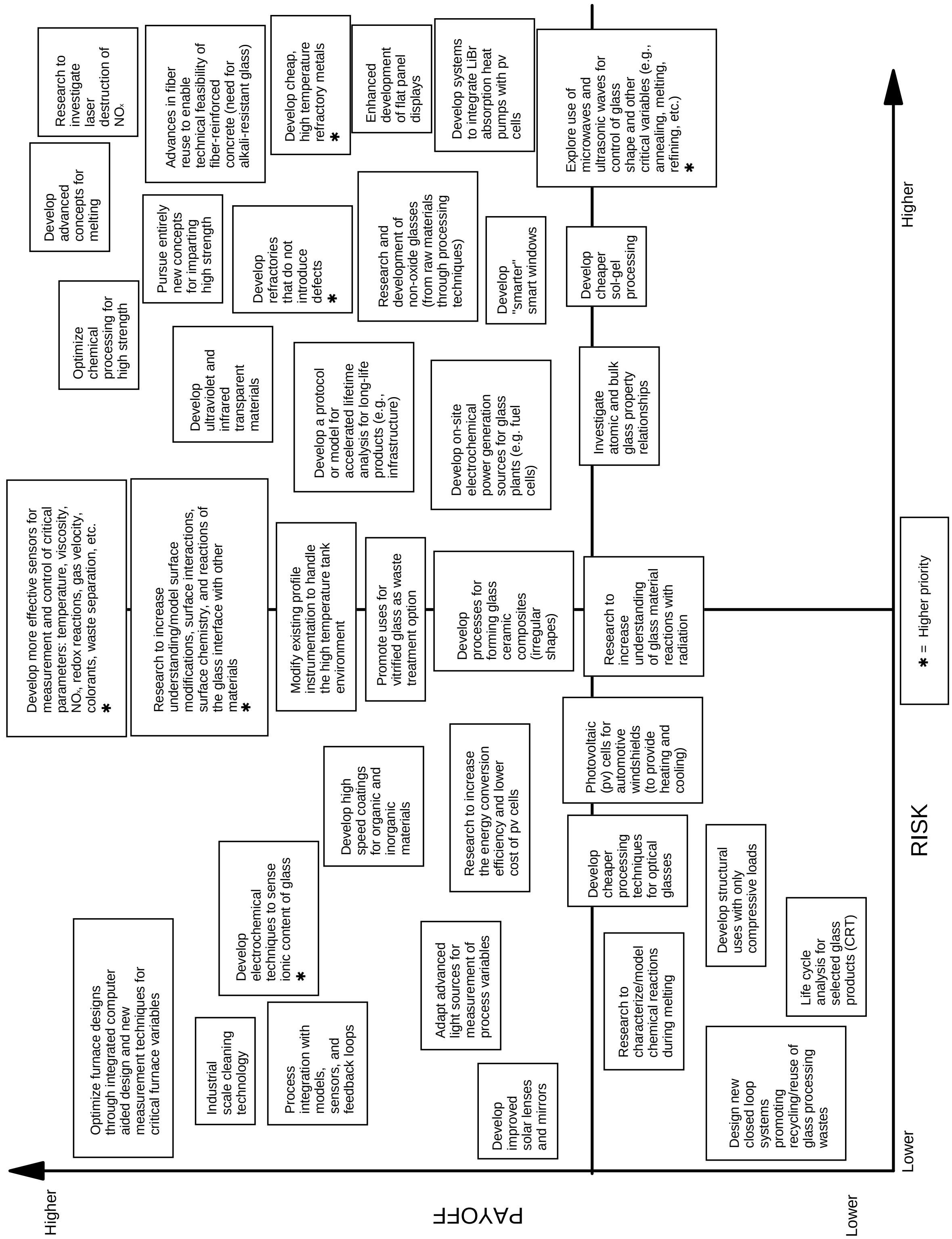
In choosing time frames, the Innovative Uses Group considered a number of elements related to market conditions and research issues. One important factor is market development (i.e., is the market already in existence, or will it need to develop over time?). The form and status of research also affects time frame. For example, if research in a particular area is already in progress, results might be expected in the near- to mid-term. The type of research needed (fundamental, engineering and development versus pilot scale) is also a good indicator of how long it might take before market impact is felt. Much of the needed research falls into the near- and mid-term time frames, which is consistent with the marketing philosophy and product development strategies of most of private industry.

Payoff and Risk

An analysis of the potential benefits of research versus the associated risks provides additional perspective for research planning. Risk is broadly interpreted as the probability that the research will result in a successful outcome, and includes all factors that could affect outcome, such as length and cost of research, development of markets, and technical barriers. Payoff is interpreted as being a measure of both commercial profitability and an increase in the use of glass for both new and existing products. The group placed research needs on a grid according to their perceived risk and payoff (shown in Exhibit 6-4).

Most research needs fall into the higher payoff category, with the entire range of risk represented. Some of the highest payoff ideas include the development of sensors for measurement and control of critical parameters; research to understand glass surface phenomenon; development of high-strength glass; and advanced melting concepts. Most of these ideas are also viewed as top research priorities.

Exhibit 6-4. Payoff vs. Risk for Innovative Uses Research



7 Summary Session

The Summary Session provided an opportunity for the individual work groups to share their results with all participants. A representative from each group presented key findings and summarized discussions on targets, technology barriers, research needs, linkages, and characteristics of priority research. The findings and recommendations of each group are described in full in Chapters 3 through 6. Following the presentations from each group, an open discussion was held to elicit general comments about the workshop process and explore the next steps in the roadmap process.

Common Research Areas

Several areas of research emerged as being important to all the work groups as well as all segments of the glass industry. An overwhelming number of these areas are related to the melting portion of the glassmaking process—the most energy-intensive and costly component of glass production. As shown in Exhibit 7-1, there is a considerable need for improved knowledge of the physical and chemical phenomena that occur during the melting process, including the combustion of fuel in the furnace, the behavior of the glass melt, and the interaction between combustion and the melt. Understanding these phenomena and their interrelationships is critical to optimizing the melting process and achieving the desired glass quality. The current lack of understanding in this area can result in inefficient furnace designs, higher than necessary energy consumption, difficulty in controlling defect rates, and the generation of excessive pollutant emissions.

Closely linked to the incomplete understanding of process behavior is the limitation of currently available sensors and controls. Advanced sensor and control systems that can effectively measure and adjust critical parameters during the melting process (e.g., temperature, viscosity, flow) will greatly improve process efficiency and more reliably control the quality of glass products. The creation of a central facility where testing and research could be performed would go a long way in fostering increased knowledge and understanding of the melt process, and would also facilitate the development of more effective sensors and controls.

Another critical need is the development of innovative new processes and furnace designs to improve the overall efficiency of the melting process. Research is needed to develop entirely new concepts for melting and refining glass, and to achieve needed improvements to existing technology. A good example is oxygen-fuel firing of the furnace, which essentially eliminates emissions of NO_x but can contribute to increased corrosion problems. To promote utilization of this environmentally sound technology, improvements are needed to reduce refractory corrosion and to more cost-effectively produce the required oxygen.

Refractory materials are an important issue for all segments of the glass industry. Current refractories have a relatively limited life and must be replaced at great expense. In addition, the used refractories may be hazardous and must be disposed of accordingly (also costly). Another problem arises as conventional refractory materials decompose and impart defects to the glass melt. The lack of cheap refractory metals is also an important issue and can preclude the development of new products and competitive pricing of current products.

Exhibit 7-1. Common Glass Industry Research Needs

	Fundamental Understanding/ Models	Materials	Sensors and Controls	Process Design
Raw Materials/ Glass Composition		Explore alternative raw materials for glass production, including substitutes for toxic glass components Design glass compositions with higher strength		
Melting/Glass Furnace	Improve understanding of combustion dynamics Increase knowledge of the physical and chemical properties of the glass melt Increase understanding of corrosion in the oxy-fuel environment Develop coupled models that simulate combustion and glass melt behavior, including emissions Establish a central research facility for combustion and furnace testing and model validation	Develop refractories with longer life and more resistance to high temperature environments Develop cost-effective alternatives to refractory metals	Develop durable, reliable, high-temperature sensors for melting parameters (e.g., temperature, viscosity, NO_x, colorants, velocity) Improve defect detection, measurement, and control Design intelligent model-based control and process optimization systems	Optimize furnace size and configuration Pursue innovative non-traditional concepts for melting and refining glass Improve oxy-fuel firing systems (corrosion control, cheaper oxygen production)

A major issue for all groups is the need for alternative raw materials for glass production. Particularly important are substitutes for the toxic or hazardous components currently used in glass, which carry environmental and regulatory burdens.

General Comments

The workshop was effective in bringing together members of the glass industry to discuss a wide variety of technology challenges and research needs. Many indicated that they were impressed with the ability of the industry to work together to identify some common goals, and considered it an outstanding achievement. Most were surprised by the commonalities identified between different segments of the industry.

The issue of industry participation and cost-sharing was emphasized by several participants. The purpose of the workshop and the roadmap process is to develop technology—in many cases this will require cost-sharing. The problem is to identify research that is important enough for corporate dollars, in view of particularly scarce research funds. In this same vein, the comment was made that industry management must become more research-oriented in order to increase the profitability of the industry. It was suggested that the U.S. Department of Energy encourage universities and non-profits to team with industry to do research, as it is difficult for them to provide cost-sharing on their own. Joint programs with universities and suppliers could also be very important and should be considered.

Several participants expressed concerns about glass research at the national laboratories. The concern was voiced that the national laboratories should not pursue research in areas that are already being pursued by industry, because potentially sensitive product development information could become available publicly. In general, the industry is reluctant to pursue collaborative research efforts because of proprietary issues.

A number of participants stated that liability issues will continue to be a major deterrent to the expansion of the glass industry, particularly in the areas of innovative glass products for infrastructure and medical/biological applications. It was suggested that this area be looked at soon to help overcome this barrier.

Next Steps

Participants identified several next steps to complete the roadmap and pursue research opportunities:

- Committees could be formed to examine common areas of interest in more depth (e.g., refractories, sensors)
- Task groups could be formed to aid implementation of the roadmap
- Industry could work collectively to lobby for funding for glass research programs
- The original subcommittees could be maintained as standing committees that provide annual input and review on technology needs
- A list of industry-wide issues could be formulated for congressman or senators
- Consensus on the roadmap document should be obtained so it can move forward

On the government side, a Request for Proposals (RFP) for pre-competitive glass research (see Appendix C for research priorities) will be issued shortly, with awards to be made in October 1997. Companies will be asked to pick and choose where they feel their research dollars will have the most impact. The concern was raised that enough time be allowed between the issuance of the RFP and submission deadlines to permit the development of a comprehensive proposal.

In addition, the glass industry technology roadmap is projected to be published by September 1997. The process will include convening the subcommittee chairs to edit and draft the roadmap, and a subsequent review of the draft by the glass industry (workshop attendees and invitees, subcommittee members).

Appendix A
Participant List

Peter Angelini
Project Manager
Oak Ridge National Laboratory

William Augsburger
Technical Director
Techneglas, Inc.

Kanwal Bhatia
Manufacturing Engineering
Ford Motor Co.

Rolf Butters
Program Manager
U.S. Department of Energy

Eugene Davis
Manager, Melting Technology
Thomson Consumer Electronics

Charles Drummond
Associate Professor
Ohio State University

Kevin Fay
Director, Safety, Health, & Environ. Affairs
PPG Industries, Inc.

Laurence Feder
Assistant Director, Program Development
Institute of Gas Technology

James Fenstermacher
Physical & Chemical Glass Specialist
Owens-Brockway Glass Container

Donald Foster
Head, New Initiatives and Partnerships
Lawrence Berkeley National Laboratory

Robert Gallagher
Manager, Remote Sensing and Industrial
Programs Department
Sandia National Laboratories

Dick Galusha
Sr. Project Melting Engineer
Corning Incorporated

Peter Gerhardinger
Research Associate
Pilkington Libbey-Owens-Ford

John Goodyear
Manager, Engineering & Research
Ford Motor Co.

Michael Greenman
Manager, Special Projects
Carr Lowrey

Michael Harris
Project Manager
Corning Incorporated

Noshir Havewala

Manager, Process Technologies

Corning Incorporated

Vincent Henry
Manager, Advanced Technology
Department, Glass Division
Ford Motor Co.

Hann-Sheng Huang
Chemical Engineer
Argonne National Laboratory

Norman Huff
Research Associate
Owens-Corning

Steve Hutchins
Engineer
Glenshaw

Ramesh Jain
Program Manager
U.S. Department of Energy

Christopher Jian
Advanced Engineer
Owens-Corning

Theodore Johnson
Team Leader, Glass
U.S. Department of Energy

Otto Jones
Mfg By-Product Manager
CertainTeed Corp.

Joe G. Keller
Advisory Engineer
Idaho National Engineering &
Environmental Laboratory

Kwaku Koram
Senior Technology Specialist
Ford Motor Co.

Jerry Kynik
Process and TQM Consultant
St. George Crystal, Ltd.

William LaCourse
Director
Center for Glass Research

Jeff Lowry
Manager, Environmental Control
Techneglas, Inc.

Daniel Lubelski
Manager, Glass Mfg. Development
Pilkington Libbey-Owens-Ford

Alex Marker
Director of Research and Development
Schott Glass Technologies Inc.

John McConnell
Manager, Special Projects
PPG Industries, Inc.

Phil Newell
Environmental Engineer
Guardian Industries Corp.

Frederic Quan
Research Contract Manager
Corning Incorporated

Philip Ross
Consultant
Glass Industry Consulting

Fred Schaeffer
Furnace Design Manager
Libbey Glass
Ronald Schroeder

Manager, Business Alliances
Praxair, Inc.

Walter Scott
Manager
PPG Industries, Inc.

James Shell
Senior Glass Technologist
Techneglas, Inc.

Charles Sorrell
Program Manager
U.S. Department of Energy

George Vachtsevanos
Professor, Electrical, Computer Engineering
Georgia Institute of Technology

Appendix B
Agenda

Glass Technology Roadmap Workshop
Agenda

April 24-25, 1997

<table>
<tr><th>Time</th><th>Activity</th><th>Organizer</th><th>Location</th></tr>
<tr><td colspan="4">Thursday, April 24</td></tr>
<tr><td>10:00 - 10:30 AM</td><td colspan="2">REGISTRATION Marcie Prince, Energetics, Inc.</td><td>Foyer to Ballroom</td></tr>
<tr><td rowspan="4">10:30 - 11:45 PM</td><td colspan="2">PLENARY SESSION</td><td rowspan="4">Ballroom Room</td></tr>
<tr><td>Welcome</td><td>Theodore Johnson, U.S. Department of Energy (DOE)</td></tr>
<tr><td colspan="2">Subcommittee Overviews

- Production Efficiency Vince Henry, Ford Motor Company
- Energy Efficiency James Shell, Techneglas
- Env. Protection/Recycling Kevin Fay, PPG Industries
- Innovative Uses Frederic Quan, Corning Glass</td></tr>
<tr><td>Instructions</td><td>Jack Eisenhauer, Energetics, Inc.</td></tr>
<tr><td>11:45 - 12:45 PM</td><td colspan="2">LUNCH</td><td>Magnolia Room</td></tr>
<tr><td>1:00 - 5:00 PM</td><td>BREAKOUT SESSIONS (includes in-room breaks)</td><td>Jack Eisenhauer, Energetics, Inc.</td><td>Assigned Meeting Rooms</td></tr>
<tr><td>6:30 - 8:30 PM</td><td colspan="2">DINNER</td><td>Lakeview I</td></tr>
</table>

Time	Activity	Organizer	Location
Friday, April 25			
7:30 - 8:00 AM`	CONTINENTAL BREAKFAST		Ballroom
8:00 - 8:15 AM	Review and Instructions	Jack Eisenhauer, Energetics, Inc.	Ballroom
8:20 - 10:30 AM	BREAKOUT SESSIONS	Jack Eisenhauer, Energetics, Inc.	Assigned Meeting Rooms
10:45 - 12:00 PM	SUMMARY SESSION	Theo Johnson, DOE	Ballroom
12:00 - 1:00 PM	LUNCH		Magnolia Room
1:00 - 3:00 PM	SUMMARY SESSION (contd.)/ CLOSING REMARKS	Theo Johnson, DOE	Ballroom
3:00 PM	ADJOURN		

Appendix C
FY 1997 Research Priorities

Production Efficiency

Research proposals are sought for technologies with the potential to improve the production efficiency of glass manufacturing, including improved manufacturing processes and new techniques that maximize glass strength and quality. Specifically, in order of decreasing priority, research is needed to develop: (1) controls for process optimization; (2A) contact and non-contact sensors; and (2B) process simulation (2A and 2B are of equal priority).

(1) ***Controls for Process Optimization*** - Advanced controls can improve production efficiency through optimization of critical process variables and control of desired glass properties. Specifically,, research is needed to develop controls which integrate multiple input variables with the objective of reducing energy consumption during glass melting and improving glass quality. Research is also needed to develop controls that can be implemented during the fabrication process to impart desired properties to the final product.

(2A) ***Contact and Non-Contact Sensors*** - Research is needed to develop contact and non-contact sensors for various parameters that are critical to the operating efficiency of the glassmaking process as well as the quality of the glass product. Areas of particular interest are sensors that will provide input on: glass physical properties; heat flux; products of fuel combustion (carbon oxides, sulfur oxides, nitrogen oxides, particulates, etc.); furnace refractory thickness and temperature; on-line stress measurements; and see-through distortion assessment, fabricated glass shape.

(2B) ***Process Simulation*** - Research is sought to develop models that simulate actual operation of glass manufacturing processes. These models can provide a cost-effective means for preliminary testing of new ideas and process modifications without high expenditures for capital or labor. Areas of interest include computer and/or physical modeling of glass melting, fuel combustion processes, coupled glass melt and fuel combustion. Also of interest is improved modeling for thermal quench processes.

Energy Efficiency

Research proposals are sought for technologies with the potential to reduce fuel use and lower energy costs in glass manufacturing. Of particular interest are technologies related to improving energy efficiency in glass melting and refining, the most energy-intensive portion of the glassmaking process. Specifically, in order of decreasing priority, research is needed to develop (1) a glass furnace with lower production costs); (2) technologies for in-situ testing of furnace refractories; (3) characterization of flames from different burner configurations; and (4) physical measurement of temperatures in glass furnaces.

(1) ***Glass Furnace with Lower Net Production Costs*** - A considerable share of production costs in glassmaking originates in the severe environment of the glass refining/melting furnace (e.g., energy use, refractories, pollution abatement, maintenance). Research is needed to significantly lower these furnace manufacturing costs, with a target cost reduction of 25 percent over typical costs. This project will have to include a glass manufacturer to provide the facility to evaluate the new technology developed. (The DOE/OIT Glass Team will help to select and provide this manufacturer.) In general, the emphasis of the research should be on technologies that improve the energy efficiency of the furnace. A major factor in energy efficiency is the transfer of energy from the fuel to the glass. As another means of lowering manufacturing costs, research could be proposed in glass batch raw materials, including the investigation of pre-processed materials (chemical or physical). Innovative furnace design changes could included methods to enhance pull rates, heat transfer, furnace life, and glass quality improvements. One area of particular interest includes the development of a cost-effective crown that can withstand the oxy-fuel combustion environment, without impacting glass quality. New furnace instrumentation and control philosophies could be developed. Finally, an enhanced waste heat recovery system should be proposed. The furnace of the future needs to have lower capital costs and may be smaller in size.

(2) ***Technologies for In-Situ Testing of Furnace Refractories -*** This project will use refractories and sample holders provided by refractory companies. U.S. glass companies will insert these refractory samples in their production furnaces. A standard test method will be developed by the participating glass companies and refractory suppliers. Proposals are requested for evaluating the refractory samples to determine the chemical and microstructural alterations during their exposure in the glass furnace. Proposals are needed for methods to determine the chemical composition of the different glass furnace gases. These gases will be different for oxy-gas furnaces versus air-gas furnaces and will also be different for the type of glass being melted. The probe for extracting the gases will need to be water cooled and able to fit into a four inch diameter hole (peep-hole).

(3) ***Combustion Laboratory Characterization of Flames From Different Burner Configurations -*** The characteristics and properties of the burner flame in the glass refining/melting furnace can have a direct influence on the energy efficiency of the furnace as well as the quality of the glass melt. Combustion laboratory research is sought to characterize the properties of flames from different burners. The laboratory must have the capability to vary the test chamber size (length, height, and width) so that it can accommodate multiple burner configurations. The ability to simulate loading is also required. Proposals for sensors and testing equipment are being solicited to make similar burner evaluations in operating glass furnaces so that the effect of the crown, glass bath, other burners and the exhaust systems can be evaluated.

(4) ***Furnace Where Mathematical Glass Bath and Combustion Space Models Can be Validated*** - The ability to optimize glass furnace design and operation can be considerably enhanced through the use of mathematical models that simulate critical elements of the glass manufacturing process. Their usefulness will be improved fit heir predicted values can be confirmed by physically measured values. Most glass furnaces have a limited number of thermocouples located in the crown and bottom of the furnace. The temperature of the glass bath at different depths is not known. Specifically, research is needed to develop techniques for the physical measurements of temperatures in the glass furnace, the temperatures in the glass bath at different depths and locations, the temperature and flow of the gases at different locations in the furnace combustion space, the chemical composition of these same gases (volatile components from the glass bath and the products of combustion), and any other properties needed to validate mathematical models for the combustion space and the glass bath. (The DOE/OIT Glass Team will assist in selecting and providing a glass furnace.)

Innovative Uses for Glass

Research proposals are sought for technologies that will create new applications for glass and enhance the use of existing glass materials. As new markets almost always require new technology, we are seeking research to develop (1) innovative glass compositions to enhance performance; (2) innovative glass processes to produce these new products; (3) new material design models to improve properties; and (4) miscellaneous technologies to support new glass applications. These four areas are listed in roughly descending priority. The proposed research should be unique, cost-effective, and practical. The latter criteria would be more important for funding decisions.

(1) ***Innovative Glass Compositions to Enhance Performance*** - Research is needed to develop glass compositions that will enhance performance properties for various applications, including: fiber reinforced composites; new acoustical materials; new thermal insulations; architectural products; solar collectors and other solar applications; optical circuit components; and flat panel displays. Both conventional melt and other techniques will be considered. Properties that are considered performance-enhancing might include (but are not limited to): low cost; thermal compatibility; increased mechanical strength; shock resistance (mechanical or thermal); materials compatibility; optical performance; less weight; and compositions that require less energy to produce.

(2) ***Innovative Glass Processes*** - Research is needed to develop innovative glass process technology for various applications, including: fiber reinforced composites; new acoustical materials; new thermal insulations; architectural products; solar collectors and other solar applications; optical circuit components; and flat panel displays.

Conventional and non-melt synthesis techniques for aerogels, foams, and other techniques will be considered. Techniques might include (but are not limited to): sol gel; chemical synthesis; chemical vapor deposition; sputtering; surface modifications to enhance processing, mechanical, chemical, or optical performance; techniques to lower costs; techniques to add mechanical strength to glass parts; and techniques to improve energy efficiency or the final product.

(3) ***New Material Design Models to Improve Properties*** - Research is needed to develop new material design models to improve the mechanical, thermal, or acoustical performance of glass, and to improve the design of composite parts or glass structures. Specifically, material design models are sought to improve material properties in the following applications: fiber reinforced composites; new acoustical materials; new thermal insulations; architectural products; solar collectors and other solar applications; optical circuit components; and flat panel displays.

(4) ***Miscellaneous Technologies to Support New Glass Applications*** - Research is needed to develop supporting technologies that are needed to enable new and innovative uses of glass in the following product areas: fiber reinforced composites; new acoustical materials; new thermal insulations; architectural products; solar collectors and other solar applications; optical circuit components; and flat panel displays. Examples of such research might include (but are not limited to) composite repair or qualification techniques, optical polarizers, light valves, and so forth.

Environmental Protection and Recycling

Research proposals are sought for technologies that will improve environmental performance, promote waste reduction and reuse, and increase glass recycling. In the area of environmental protection, in order of decreasing priority, research is needed to develop (1) improved oxy-fuel firing technology to reduce air emissions; and (2) alternative raw materials, batch preparation, and/or furnace designs with lower particulate and gaseous emissions. In the recycling area, in order of decreasing priority, research is needed to (1) improve sorting and preparation of post-consumer wastes; and (2) develop reliable outlets for used refractories.

Environmental Protection

(1) ***Improved Oxy-fuel Firing Technology to Reduce Air Emissions -*** The use of oxy-fuel firing technology in glass furnaces can significantly reduce pollutant air emissions and pollution abatement costs. The use of this technology is not widespread, however, due to marginal economics and possible side-effects on furnace refractories. Lowering the lb/hour emission rate can also create side-effects (increased opacity, higher concentration in lower volume) which cause other compliance problems. Research is needed to develop technologies that will address these problems and increase the use of oxy-fuel firing in the industry. Specific areas of interest include: lower cost oxygen generating technology; control of refractory corrosion resulting from oxy-fuel firing; and reduction in side-effects leading to other compliance problems.

(2) ***Alternative Raw Materials, Batch Preparation, and/or Furnace Designs With Lower Particulate and Gaseous Emissions*** - Research is needed to develop alternative raw materials, batch preparation, batch preheating, and/or improved furnace designs that lower particulate and gaseous emissions, particularly for those cases where oxy-fuel firing is not practical. Research might include (but is not limited to) computer modeling of furnace designs, improved process and/or furnace design, batch consolidation by pelletizing or preheating to lower energy requirements, and development of alternative raw materials that reduce emissions.

Recycling

(1) ***Improve Sorting and Preparation of Post-Consumer Wastes*** - There is a need to develop an "umbrella" approach to improve the sorting and preparation of post-consumer wastes *of all types*. Such an approach will benefit not only the glass industry but other industries involved in recycling (e.g., aluminum, iron and steel, paper and plastics). Improved preparation processes for post-consumer glass could increase the amount of cullet (recycled glass) used to create acceptable quality glass products and increase the use of recycled glass in general. For the glass industry, research is sought to address two key areas: complete automatic color separation; and removal of all non-glass contaminants.

(2) ***Develop Reliable Outlets for Used Refractories*** - Some of the used refractories from glass furnaces are considered to be hazardous, which makes disposal difficult and costly. Research is needed to develop new processing techniques which allow the reuse of used refractories, to investigate alternatives to disposal, and to develop new markets for the use of these refractories.

Appendix D
Plenary Presentations

Exhibit D-1. Production Efficiency Presentation

Production Efficiency

MEMBERS OF THE PRODUCTION EFFICIENCY SUBCOMMITTEE

NAME	ORGANIZATION
KWAKU KORAM	FORD MOTOR CO.
JOHN MCCONNELL	PPG INDUSTRIES
HARRY RUSSEL	SCHULLER INT'L
FRED SCHAEFFER	LIBBEY GLASS
DON SHAMP	SCHULLER INT'L
CHARLES SORRELL	OIT GLASS TEAM

MEMBERS OF THE PRODUCTION EFFICIENCY SUBCOMMITTEE

NAME	ORGANIZATION
KANWAL BHATIA	FORD MOTOR CO.
R. EUGENE DAVIS	THOMSON CONSUMER ELECTRONICS
CHRISTOPHER JIAN	OWENS-CORNING
DONALD FOSTER	LAWRENCE BERKELEY LAB.
EDWARD GALLAGHER	U.S. DOE-CHICAGO
ROBERT GALLAGHER	SANDIA NATIONAL LAB.
PETER GERHARDINGER	PILKINGTON-LOF
MARV GRIDLEY	BALL-FOSTER
MIKE HARRIS	CORNING
VINCENT HENRY	FORD MOTOR CO.

INTRODUCTION

KEY CHALLENGES FACING THE INDUSTRY ARE:

INCREASED COMPETITIVE PRESSURES

FROM ALTERNATIVE MATERIALS

FROM EXTERNAL GLASS MANUFACTURERES

HIGH CAPITAL AND LABOR COSTS

ENVIRONMENTAL PRESSURES

Exhibit D-1. Production Efficiency Presentation (cont.)

BUSINESS OUTLOOK

- NEW RESEARCH AND DEVELOPMENT PROGRAMS ARE ESSENTIAL TO BUSINESS GROWTH AND SURVIVAL
- SIGNIFICANT PROGRESS TOWARDS BECOMING MORE COMPETITIVE AND IMPROVING OVERALL EFFICIENCIES MAY BY REALIZED THROUGH PRODUCTION EFFICIENCY IMPROVEMENTS

PRODUCTION EFFICIENCY OBJECTIVE

PRODUCE MORE QUALITY GLASS PRODUCTS IN A TIMELY MANNER AT LOWER COSTS, WITHOUT ADVERSELY IMPACTING ENVIRONMENTAL EMISSIONS.

KEY OBJECTIVES

- OPERATE WITH PRODUCTION COSTS AT LEAST 20% BELOW 1995 LEVELS
- DEVELOP AND IMPLEMENT NEW PRODUCTION TECHNOLOGIES TO:
  - REDUCE PRODUCTION COSTS
  - IMPROVE PRODUCT QUALITY
  - REDUCE TIME TO MARKET OF GLASS MANUFACTURING PROCESSES.
- REDUCE PROCESS ENERGY USE FORM PRESENT FACILITY LEVELS BY 50% TOWARDS THEORETICAL ENERGY USE LIMITS.

RESEARCH OBJECTIVES

- PRODUCTION EFFICIENCY SUBCOMMITTEE HAS IDENTIFIED FOCUS AREAS CRITICAL FOR TECHNOLOGICAL IMPROVEMENTS IN PRODUCTION EFFICIENCY
- TECHNOLOGY AREAS FURTHER DIVIDED INTO:
  - PRE-COMPETITIVE
  - POST-COMPETITIVE

SUMMARY OF SUBCOMMITTEE ACTIVITIES

BASED ON DISCUSSIONS, RECOGNIZED THE COMMON AREAS LEADING TO INCREASED PRODUCTION EFFICIENCY

A SURVEY FROM CIRCULATED FOR FURTHER IDENTIFICATION OF PRIORITIES

THIS LED TO DETERMINATION OF MORE DETAILS DESIRED IN EACH OF THE RECOGNIZED AREA

MORE DISCUSSIONS NEEDED BEFORE PLANS ARE FINALIZED

STATUS

HELD FOUR MEETINGS TO SET PRIORITIES IN DEVELOPING DETAILED RESEARCH PROTFOLIO

ADDITIONAL STAKEHOLDERS HAVE BEEN SOLICITED FROM DIFFERENT SEGMENTS OF GLASS INDUSTRY

BUILDING A COALITION OF INDUSTRY, ACADEMIA, AND GOVERNMENT AGENCIES

Exhibit D-2. Energy Efficiency Presentation

TECHNEGLAS

ENERGY EFFICIENCY AND CONSERVATION

DR. JAMES A. SHELL

Techneglas is a member of
Electronic Industries Association

ENERGY EFFICIENCY AND CONSERVATION

- ☺ OPTIMIZING ELECTRIC BOOST TO REDUCE TOTAL ENERGY CONSUMPTION
- ☺ IMPROVING FURNACE DESIGN AND OPERATION TO MAXIMIZE COMBUSTION EFFICIENCY
- ☺ RECOVERING AND REUSING WASTE HEAT FROM OXY-FUEL FURNACES
- ☺ PRODUCING OXYGEN MORE EFFICIENTLY FOR OXY-FUEL FIRING

ENERGY EFFICIENCY AND CONSERVATION

- ☺ GLASS INDUSTRY USES THREE MAJOR TYPES OF FURNACES
  - ❖SIEMAN' S REGENERATIVE FURNACES
  - ❖DIRECT FIRED
  - ❖ALL ELECTRIC FURNACES

ENERGY EFFICIENCY AND CONSERVATION

- ☺ SIEMAN'S REGENERATIVE FURNACES (AIR / FUEL)
  - ❖END - FIRED
  - ❖SIDE - PORT
  - ❖ELECTRIC AND OXYGEN BOOST

ENERGY EFFICIENCY AND CONSERVATION

- ☺ ADVANTAGES OF SIEMAN'S REGENERATIVE FURNACES
  - ❖OPERATIONAL EXPERIENCE - SIEMAN'S PATENT 1860
  - ❖ LONG FURNACE LIFE

ENERGY EFFICIENCY AND CONSERVATION

- ☺ DISADVANTAGES OF REGENERATIVE FURNACES
  - ❖HIGHER LEVELS OF NO_x
  - ❖ HIGHER CAPITAL COSTS DUE TO REGENERATORS

Exhibit D-2. Energy Efficiency Presentation (cont.)

ENERGY EFFICIENCY AND CONSERVATION

- RESEARCH ACTIVITY - METHODS TO REDUCE NOx
  - Oxygen Enriched Air Staging (Minimizes NOx Generation)
  - Post Melter gas Reburn (Destroys the NOx in the Regenerators)
  - Improving Furnace Design and Operation to Maximize Combustion Efficiency

ENERGY EFFICIENCY AND CONSERVATION

- DIRECT FIRED FURNACES (OVER 90 ARE GAS / OXY)
- ADVANTAGES OF GAS / OXY
  - » FUEL REDUCTION (15 % TO 40 %)
  - » SUBSTANTIAL NOx REDUCTION
  - » SUBSTANTIAL PARTICULATE REDUCTION
  - » CAPITOL COST REDUCTION

ENERGY EFFICIENCY AND CONSERVATION

- DIFFICULTIES WITH USING OXY / FUEL MELTING
  - COMBUSTION ATMOSPHERE
    - HIGHER CONCENTRATIONS - CO2, H2O, & ???
    - NITROGEN IS NOT IN THERE
  - REFRACTORIES
    - CROWN CORROSION
    - BREASTWALL CORROSION

ENERGY EFFICIENCY AND CONSERVATION

- DIFFICULTIES WITH USING OXY / FUEL MELTING
  - EXHAUST & FURNACE PRESSURE
  - FURNACE GRADIENTS / OPERATION EXPERIENCE
  - FOAM ON GLASS SURFACES

ENERGY EFFICIENCY AND CONSERVATION

- RESEARCH ACTIVITIES - OXY / FUEL FURNACES
  - » IMPROVED CROWN AND BREASTWALL REFRACTORIES
  - » BETTER BURNERS
  - » EQUIPMENT FOR RECOVERING AND REUSING WASTE HEAT
  - » PRODUCING OXYGEN MORE EFFICIENTLY

ENERGY EFFICIENCY AND CONSERVATION

- ALL ELECTRIC FURNACES
  - HIGH HEATING EFFICIENCY (ELECTRODES ARE IN GLASS)
  - NO NOx AND PARTICULATE EMISSIONS
  - HIGH COST OF ELECTRICAL ENERGY
  - VERY SHORT FURNACE LIFETIME (RAPID LOSS OF REFRACTORIES)

Exhibit D-2. Energy Efficiency Presentation (cont.)

ENERGY EFFICIENCY AND CONSERVATION

- ALL ELECTRIC FURNACES - RESEARCH NEEDS
  - CHEAPER ELECTRICITY
  - IMPROVED ELECTRICAL SYSTEMS
    - BETTER ELECTRODE MATERIALS
    - TEMPERATURE SENSORS FOR VULNERABLE AREAS
    - BETTER REFRACTORIES
    - ADVANCE CONTROL SYSTEMS
    - IMPROVED MELTER DESIGNS
      - MODELING TO DETERMINE OPTIMUM ELECTRODE LOCATION

ENERGY EFFICIENCY AND CONSERVATION

- HIGHEST PRIORITY RESEARCH PROJECTS
  - REFRACTORIES FOR CROWNS & BREASTWALLS
  - MODELING - PHYSICAL VALIDATION OF MATHEMATICAL MODELS

ENERGY EFFICIENCY AND CONSERVATION

- ROUND ROBIN REFRACTORY TESTING
  - REFRACTORY COMPANIES WILL DONATE ONE INCH CORE SAMPLES
  - GLASS COMPANIES WILL INSTALL 4 SAMPLES WITH HOLDER IN GLASS FURNACE OPENINGS. VARIOUS GLASS TYPES.
  - INITIAL TESTS WILL BE FOR 30 DAYS.
  - OAK RIDGE AND REFRACTORY COMPANIES WILL EXAMINE THE SAMPLES.

Exhibit D-3. Environmental Protection and Recycling Presentation

Environmental Protection and Recycling

Team Members

- Jerry Bannister, Owens-Brockway
- Kevin Fay, PPG Industries
- Michael Greenman, Carr-Lowrey
- Duane Hanson, Idaho Nat'l Energy Lab
- Foster Harding, Schuller
- Jeff Lowry, Techneglas
- Tony Rizzo, Lennox Crystal
- Merrill Smith, U.S. Department of Energy

Activity to Date

- Team formed last summer
- Conference calls to brainstorm needs
- Summaries by glass segment
  - Flat, Container, Fiber Glass, Specialty
- Workshop at Columbus in October
- R&D project needs updated in January
- Report given at February workshop

Environmental Protection Highest Priority Need

- "Develop improved oxy-fuel firing technology to reduce air emissions" (focus on avoiding creation of emissions versus cleaning up afterward)
  - lower cost oxygen technology
  - refractory corrosion control
  - emission concentration issues

Environmental Protection Medium Priority Need

- "Develop alternative raw materials, batch preparation, batch preheating and/or improved furnace designs that lower particulate and gaseous emissions"
  - regulations based upon total emissions per ton-hour, not on concentration
  - computer modeling of furnace designs

Environmental Protection Lower Priority Needs

- New abatement technologies (low)
- New manufacturing processes that generate less solid waste (low)
- Reuse waste water and solids (low)
- Lower VOC emissions - F.G. binders (high for one segment, low for rest)

Exhibit D-3. Environmental Protection and Recycling Presentation (cont.)

Recycling Highest Priority Need

- "Improvements in sorting and preparation of post-consumer wastes"
  - An overall "umbrella" approach is preferred over addressing needs on an individual basis. This would impact at least 5 of the 7 Industries of the Future in DOE's program.

Recycling Highest Priority Need (cont.)

- Specific glass industry recycling needs
  - complete automatic color separation
  - removal of all non-glass contaminants
  - new cullet markets - higher value

Recycling Medium Priority Need

- Reliable outlets for used refractories
  - develop more markets
  - assure high quality from reprocessed materials

Exhibit D-4. Innovative Uses for Glass Presentation

Innovative Uses for Glass

- *Jon Bauer*
- *Edward Boulos*
- *Jacqueline LaBarre*
- *Terry Lusher*
- *Fred Millett*
- *Fred Quan*

- *Schuller International*
- *Ford Glass*
- *Corning-Asahi Video*
- *Pilgrim Glass*
- *Libby Owens Ford*
- *Corning Incorporated*

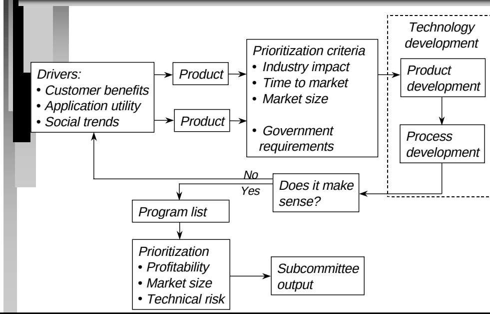
Glass Industry Needs New Products

- *Too many mature products*
- *Need higher margin product mix*
- *Traditionally very little support for R&D*
- ***INNOVATION** needed!*

Technology Roadmap Effort

- *Seek new applications for glass*
  - *Higher technical content*
  - *Positive impact on industry*
- *How do we get there from here?*
- *Opportunity to leverage Technology*
  - *Government*
  - *National laboratories*

Diagram of Technology Roadmap



How Do We Predict the Future?

- *Make reasonable assumption*
- *Brainstorming session - industry input*
- *Glass problems conference add-on*
  - *October 10, 1996, 30-40 participants*
- *Formulated:*
  - *Driving influences*
  - *Products*
  - *Processes*

Organized Brainstorming Results

- ***Materials Related***
- *New Compositions*
  - *Optical Properties*
- *New Coatings*
- *Material Interfaces*
  - *Leaching*
  - *Durability*
  - *Controlled Crystallization*
  - *Strength*
  - *Friction Reduction*
- *New or Improved Properties*
- *Laser Host Material*
- *Hybrid Materials*
- *Self-Healing/ Repairable Materials*
- *Hi-Dielectric Materials*
- *Molecular Modelling Requirements*
- *New Sources of Raw Materials*
- *Composites*

- ***Transport Related***
- *Ground Based*
  - *New IC Engines*
  - *Hybrid Vehicles*
  - *Alternate Fuels*
  - *Light weight*
  - *Intelligent Vehicles*
- *Marine Based*
  - *Submarines*
  - *Ships*
- *Hi-Speed Transport - Aircraft*
- *Space Applications (NASA)*
- *Public Transportation*
  - *Fast*
  - *Convenient*
- *Street Markings*

Exhibit D-4. Innovative Uses Presentation (cont.)

Organized Brainstorming Results (cont.)

- ***Process Related***
  - *New Methods of Heating Glass*
  - *Near Net Shape Manufacturing*
  - *Less Hydrocarbon Fuels Available*
    - *(Other ways to make glass)*
  - *Other Furnance Applications*
    - *(What other products can be made in the furnance)*
  - *Faster, Hi-speed Production*
- ***Building Related***
  - *Future Housing*
    - *Transparency*
    - *Energy Saving*
  - *Architectural Glass*
    - *Artistic Designs*
  - *Light Delivery System*
  - *IR Heat Delivery Systems*
  - *Advanced Climatic Controls*
- ***Social Needs***
  - *Underwater Communities*
  - *Waste Regeneration*
  - *Holograms, Entertainment Needs*
  - *Solar Power Needs*
  - *Space Station-Space Construction*
- ***Health & Medical***
  - *Medical Applications - Cures, Delivery, Sensors*
  - *Prevention of Disease*
  - *Self-Cleaning Ability*
  - *Biodegradable Glass*
  - *Bioimplants*

Organized Brainstorming Results (cont.)

- ***Miscellaneous***
  - *Sensor Needs*
  - *Catalysis*
    - *Reuse Incinerator Ash*
    - *Nuclear Waste*
    - *Chemically Hazardous*
  - *Opto-electronic Devices*
    - *Microstructures*
    - *Interconnects*
    - *Optical Storage*
  - *Micro-Tagging*
  - *New Industrial Applications*
- ***Chemical Needs***
  - *Inert, dielectric*
  - *Controlled Solubility*
  - *Controlled Release*

Product

Sun Power

Photovoltaic Car Roofs (see through)
Solar lenses and mirrors
Porous Substrates - Solar
Architectural photovoltaics

Structural

Glass Structural products
Furniture
Fiberglass reinforced Composite Materials
New Acoustical Materials
New Thermal Insulations
Glass Polymer Composites
Architectural Glass
Foam Glass Roofing
Fireproof Materials - Clothing
Self extinguishing fire materials
Fire Rated Glass
Roadbed Materials
Flooring materials
Premolded Kiosks
Privacy Glass
Lightweight Glass
Partitions - Marking Board
Cleanable

Electrical or electronic

Optical Security Devices
Opto-electronic Devices
CRT Displays
Flat Panel Displays
Labeling System Integrated in Container
New Laser Materials
Transparent Walls w/Integrated Displays
Electrochromic Switchable Glass

High Strength/Special Properties

Unbreakable Glass
Containers that Bounce
Self-Healing/Repairable Glass
Flexible Glass
Deformable glass
Metallic Glass - Hi-Strength
Glass Bearings

Biological/Medical

Large Sterilizable Services
Glass/Bone Implants (FRITS)

Miscellaneous

Controlled Porosity Glass
Filters
Hydrothermal Piping
Food Packaging/Preparation
Glass Applications in Clean-up/Recycling
Eyeglasses
Fashion - Jewelry
Foam Storage of Gases
Write-Resistance Surfaces
Permanent Glass Spray
Catalytic Substrate
Agri-glass Products (controlled release)

Process

Fabrication/Forming

Sense new parameters
New Forming Techniques
Defect control
NEw methods of heating glass
Flame chemistry
Alternative Fuel Sources
Reduction of CO_2 & ozone
Leaching
Ion Exchange
Virtual Processing
Advanced Chemical Synthesis
Sol-Gel
CVD
Controlled Atmosphere
Surface Modification
New Methods of Coating Glass
Using Glass for Coatings

Attachment

Joining Techniques
Glass Sealing Procedures

Analysis

Micro Analytical Technology
Computer Aided Design
Gowing Glass/Ceramic Structures
Phase Diagrams Visualization
Computer Design of Materials

Miscellaneous

Gases Separation
Liquid Separation
In-situ Vitrification